Application Manual

Line Differential Protection and Control RED615

Document ID: 1MRS756498
Issued: 03.10.2008
Revision: A
Product version: 1.1

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This product complies with the directive of the Council of the European Communities on the approximation of the laws of the Member States relating to electromagnetic compatibility (EMC Council Directive 2004/108/EC) and concerning electrical equipment for use within specified voltage limits (Low-voltage directive 2006/95/EC). This conformity is the result of a test conducted by ABB in accordance with Article 10 of the directive in agreement with the product standards EN 50263 and EN 60255-26 for the EMC directive, and with the product standards EN 60255-6 and EN 60255-27 for the low voltage directive. The IED is designed in accordance with the international standards of the IEC 60255 series.

Table of contents

Section 1 Introduction

1.1 This manual

Application Manual contains application descriptions and setting guidelines sorted per function. The manual can be used to find out when and for what purpose a typical protection function can be used. The manual can also be used when calculating settings.

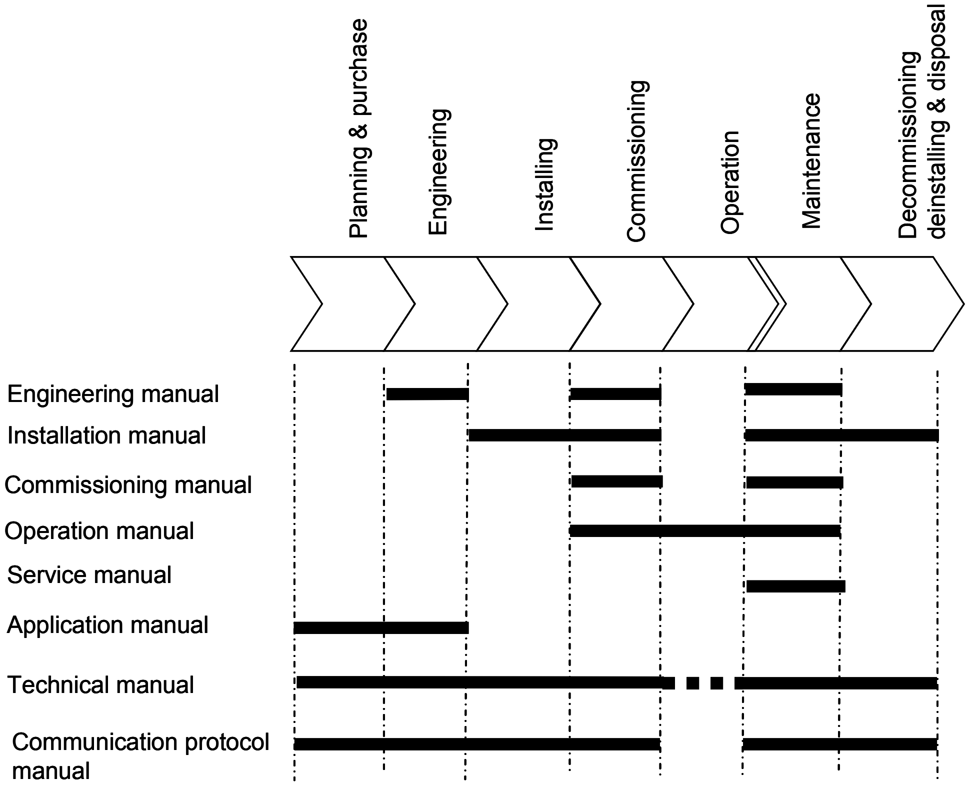
1.2 Intended audience

This manual addresses the protection and control engineer responsible for planning, pre-engineering and engineering.

The protection and control engineer must be experienced in electrical power engineering and have knowledge of related technology, such as communication and protocols.

1.3 Product documentation

1.3.1 Product documentation set



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Engineering Manual contains instructions on how to engineer the IEDs. The manual provides instructions on how to use the different tools for IED engineering. It also includes instructions on how to handle the tool component available to read disturbance files from the IEDs on the basis of the IEC 61850 definitions. It further introduces the diagnostic tool components available for IEDs and the PCM600 tool.

Installation Manual contains instructions on how to install the IED. The manual provides procedures for mechanical and electrical installation. The chapters are organized in the chronological order in which the protection IED should be installed.

Commissioning Manual contains instructions on how to commission the IED. The manual can also be used as a reference during periodic testing. The manual provides procedures for energizing and checking of external circuitry, setting and configuration as well as verifying settings and performing directional tests. The chapters are organized in the chronological order in which the IED should be commissioned.

Operation Manual contains instructions on how to operate the IED during normal service once it has been commissioned. The manual can be used to find out how to handle disturbances or how to view calculated and measured network data in order to determine the cause of a fault.

Service Manual contains instructions on how to service and maintain the IED. The manual also provides procedures for de-energizing, de-commissioning and disposal of the IED.

Application Manual contains application descriptions and setting guidelines sorted per function. The manual can be used to find out when and for what purpose a typical protection function can be used. The manual can also be used when calculating settings.

Technical Manual contains application and functionality descriptions and lists function blocks, logic diagrams, input and output signals, setting parameters and technical data sorted per function. The manual can be used as a technical reference during the engineering phase, installation and commissioning phase, and during normal service.

The Communication Protocol manuals describe the different communication protocols supported by the IED. The manuals concentrate on vendor-specific implementations.

The Point List Manual describes the outlook and properties of the data points specific to the IED. This manual should be used in conjunction with the corresponding Communication Protocol Manual.

All manuals are not available yet.

1.3.2 Document revision history

Document revision/date	Product version	History
A/03.10.2008	1.1	First release

The latest revision of the document can be downloaded from the ABB web site http://www.abb.com/substationautomation

1.3.3 Related documentation

Name of the document	Document ID
Modbus Communication Protocol Manual	1MRS756468
Installation Manual	1MRS756375
Operation Manual	1MRS756499
Technical Manual	1MRS756497
CT dimensioning, Application Note and Setting Guide	1MRS756683

1.4 Document symbols and conventions

1.4.1 Safety indication symbols

This publication includes the following icons that point out safety-related conditions or other important information:

The electrical warning icon indicates the presence of a hazard which could result in electrical shock.

The warning icon indicates the presence of a hazard which could result in personal injury.

The caution icon indicates important information or warning related to the concept discussed in the text. It might indicate the presence of a hazard which could result in corruption of software or damage to equipment or property.

The information icon alerts the reader to relevant facts and conditions.

The tip icon indicates advice on, for example, how to design your project or how to use a certain function.

Although warning hazards are related to personal injury, it should be understood that operation of damaged equipment could, under certain operational conditions, result in degraded process performance leading to personal injury or death. Therefore, comply fully with all warning and caution notices.

1.4.2 Document conventions

The following conventions are used for the presentation of material:

- Abbreviations in this manual are spelled out in the section "Glossary". In addition, the section contains descriptions on several terms.
- Push button navigation in the HMI menu structure is presented by using the push button icons, for example:
  To navigate between the options, use and .
- HMI menu paths are presented as follows:
  Select **Main menu/Configuration/HMI**.
- Menu names are shown in bold in WHMI, for example:
  Click **Information** in the WHMI menu structure.
- HMI messages are shown in Courier font, for example:
  To save the changes in non-volatile memory, select `Yes` and press
- Parameter names are shown in italics, for example:
  The function can be enabled and disabled with the *Operation* setting.
- Parameter values are indicated with quotation marks, for example:
  The corresponding parameter values are "On" and "Off".
- IED input/output messages and monitored data names are shown in Courier font, for example:
  When the function starts, the `START` output is set to TRUE.

1.4.3 Functions, codes and symbols

Table 1: Functions included in the RED615 standard configuration

Function	IEC 61850	IEC 60617	ANSI
Line differential protection, stabilized low stage and instantaneous high stage	LNPLDF	3ΔI >, 3ΔI>>	87L
Three-phase non-directional overcurrent protection, low stage	PHLPTOC1	3I>	51P-1
Three-phase non-directional overcurrent protection, high stage	PHHPTOC1	3I>>	51P-2
Three-phase non-directional overcurrent protection, instantaneous stage	PHIPTOC1	3I>>>	50P/51P
Negative-sequence overcurrent protection	NSPTOC1	I_2>	46
Circuit breaker failure protection	CCBRBRF1	3I>/I_0>BF	51BF/51NBF
Three-phase inrush detector	INRPHAR1	3I2f>	68
Binary signal transfer	BSTGGIO	BST	BST
Circuit breaker control with interlocking	CBXCBR	I ↔ O CB	-
Three-phase current measurement	CMMXU1	3I	3I
Sequence current measurement	CSMSQI1	I_1, I_2, I_0	I_1, I_2, I_0
Transient disturbance recorder	RDRE1	-	-
Table continues on next page			

Function	IEC 61850	IEC 60617	ANSI
Trip circuit supervision	TCSSCBR1	TCS	TCM
Current circuit supervision	CCRDIF1	MCS 3I	MCS 3I
Protection communication supervision	PCSRTPC1	PCS	PCS

Section 2 RED615 overview

2.1 Overview

RED615 is a two terminal phase segregated line differential protection IED designed for the protection, measurement and supervision of feeders in utility substations and industrial power systems. Re-engineered from the ground up, the IED has been guided by the IEC 61850 standard for communication and interoperability of substation automation devices.

The IED provides unit type main protection for overhead lines and cable feeders in distribution networks. The IED also features current-based protection functions for remote back-up to the down stream protection relays and local back-up for the line differential main protection.

The IED is adapted for the protection of overhead line and cable feeders in isolated neutral, resistance earthed, compensated (impedance earthed) and solidly earthed networks. Once the standard configuration IED has been given the application-specific settings, it can directly be put into service.

The 615 series IEDs support a range of communication protocols including IEC 61850 with GOOSE messaging and Modbus®.

2.1.1 Product version history

IED version	Release date	Product history
1.1	03.10.2008	Product released

2.1.2 PCM600 and IED connectivity package version

Supported tools:

- Protection and Control IED Manager PCM600 Ver. 2.0 SP1 or later
- RED615 Connectivity Package Ver. 1.0
    - Parameter Setting Tool
    - Disturbance Handling Tool
    - Signal Monitoring Tool

- Signal Matrix Tool
- Communication Management Tool
- Differential Characteristics Tool

Download connectivity packages from the ABB web site http://www.abb.com/substationautomation

2.2 Operation functionality

2.2.1 Standard configurations

The line differential protection IED RED615 supports the following functions:

Standard configuration functionality	Std. conf. A (DE01)
Protection	
Line differential protection and related measurements, stabilized low-set stage	•
Line differential protection and related measurements, instantaneous high-set stage	•
Three-phase non-directional overcurrent, low-set stage	•
Three-phase non-directional overcurrent, high-set stage, instance 1	•
Three-phase non-directional overcurrent, high-set stage, instance 2	•
Three-phase non-directional overcurrent, instantaneous stage	•
Negative-sequence overcurrent, instance 1	•
Negative-sequence overcurrent, instance 2	•
Circuit breaker failure protection	•
Three-phase inrush current detection	•
Binary signal transfer	•
Control	
Circuit breaker control with interlocking	•
Supervision and Monitoring	
Trip-circuit supervision of two trip circuits	•
Local and remote phase currents (protection co-ordinated)	•
Current circuit supervision	•
Protection communication supervision	•
Measurement	
Transient disturbance recorder	•
Three-phase current measurement	•

Table continues on next page

Current sequence components	•
Differential current measurement	•
Bias current measurement	•

2.2.2 Optional functions

The optional functions available in the IED are:

- Modbus TCP/IP or RTU/ASCII

2.3 Physical hardware

The IED consists of two main parts: plug-in unit and case. The plug-in unit content depends on the ordered functionality.

Table 2: Plug-in unit and case

<table>
<tr><th>Main unit</th><th colspan="2">Content options</th></tr>
<tr><td rowspan="5">Plug-in unit</td><td colspan="2">HMI</td></tr>
<tr><td colspan="2">CPU module</td></tr>
<tr><td>Auxiliary power/ binary output module (slot X100)</td><td>48-250V DC / 100-240 V AC
2 normally-open PO contacts
1 change-over SO contacts
1 normally open SO contact
2 double-pole PO contacts with TCS
1 dedicated internal fault output contact</td></tr>
<tr><td>AI module (slot X120)</td><td>3 phase current inputs (1/5A)
1 residual current input (1/5A)
4 BIs</td></tr>
<tr><td>BI/O module (slot X110)</td><td>7 BIs
3 SO contacts</td></tr>
<tr><td rowspan="2">Case</td><td>Optional BI/O module (slot X130)</td><td>6 BIs
3 SO contacts</td></tr>
<tr><td colspan="2">AI module interface connectors
Auxiliary power/binary output module interface connectors
BI/O module interface connectors
Communication module</td></tr>
</table>

The rated input levels are selected in the IED software for phase current and residual current. The binary input thresholds 18...176 V DC are selected by adjusting the IED's parameter settings.

The connection diagrams of different hardware modules are presented in this manual.

See the Installation Manual for more information about the case and the plug-in unit.

2.4 LHMI

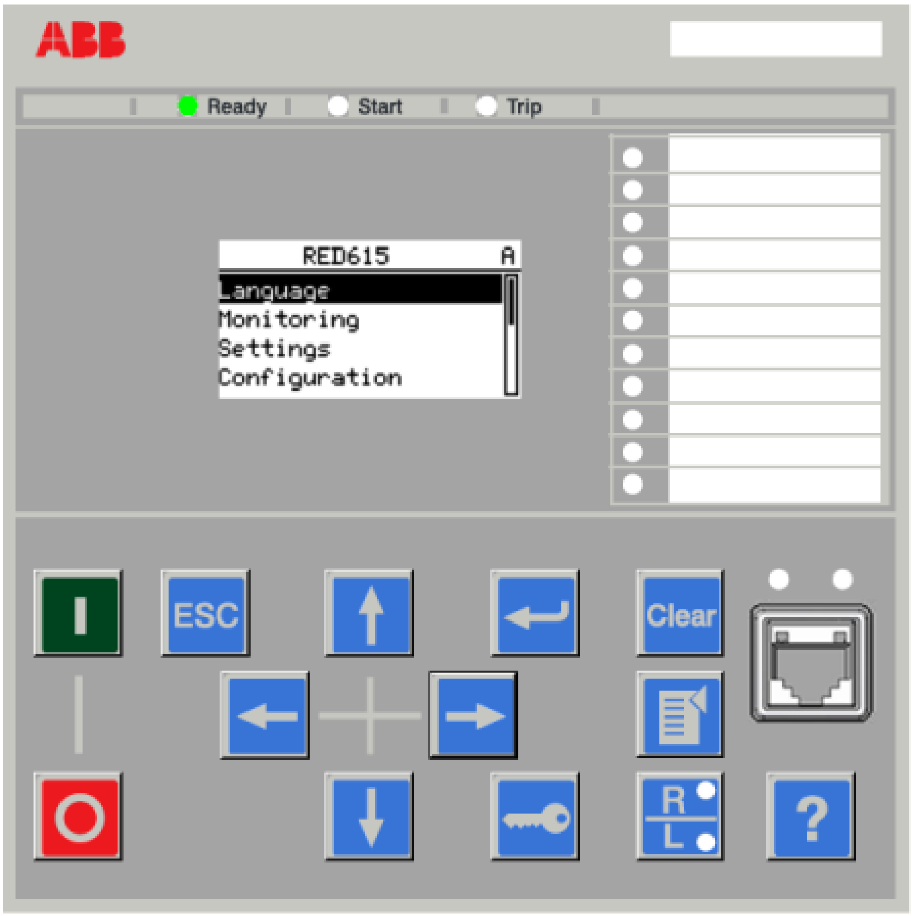


Figure 1: LHMI

The LHMI of the IED contains the following elements:

- Display
- Buttons
- LED indicators
- Communication port

The LHMI is used for setting, monitoring and controlling.

2.4.1 LCD

The LHMI includes a graphical LCD that supports two character sizes. The character size depends on the selected language.

The amount of characters and rows fitting the view depends on the character size:

Character size	Rows in view	Characters on row
Small, mono-spaced (6x12 pixels)	5 rows 10 rows with large screen	20
Large, variable width (13x14 pixels)	4 rows 8 rows with large screen	min 8

The display view is divided into four basic areas:

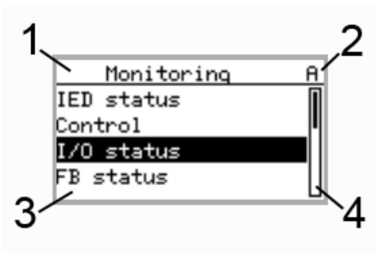


Figure 2: Display layout

1 Header

2 Icon

3 Content

4 Scroll bar (appears when needed)

2.4.2 LEDs

The LHMI includes three protection indicators above the display: Ready, Start and Trip.

There are also 11 matrix programmable alarm LEDs on front of the LHMI. The LEDs can be configured with PCM600 and the operation mode can be selected with the LHMI.

2.4.3 Keypad

The LHMI keypad consists of push buttons which are used to navigate in different views or menus. With push buttons you can give open or close commands to one primary object, for example, a circuit breaker, disconnector or switch. The push

buttons are also used to acknowledge alarms, reset indications, provide help and switch between local and remote control mode.

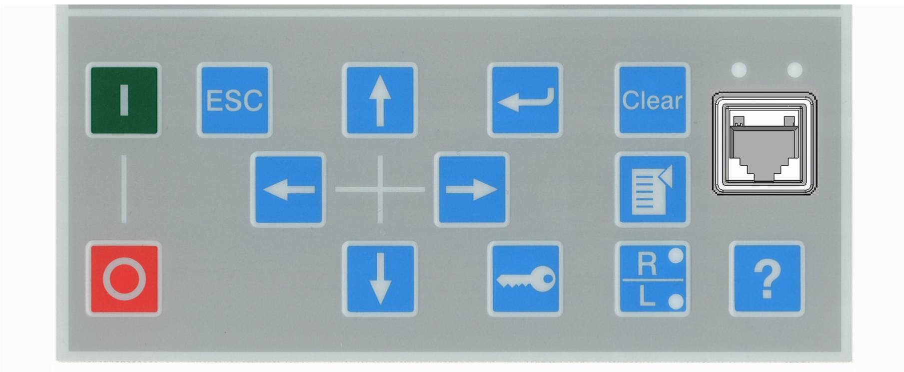


Figure 3: LHMI keypad with object control, navigation and command push buttons and RJ-45 communication port

2.5 WHMI

The WHMI enables the user to access the IED via a web browser.

WHMI is disabled by default.

WHMI offers the following functions:

- Alarm indications and event lists
- System supervision
- Parameter settings
- Measurement display
- Phasor diagram

The menu tree structure on the WHMI is identical to the one on the LHMI.

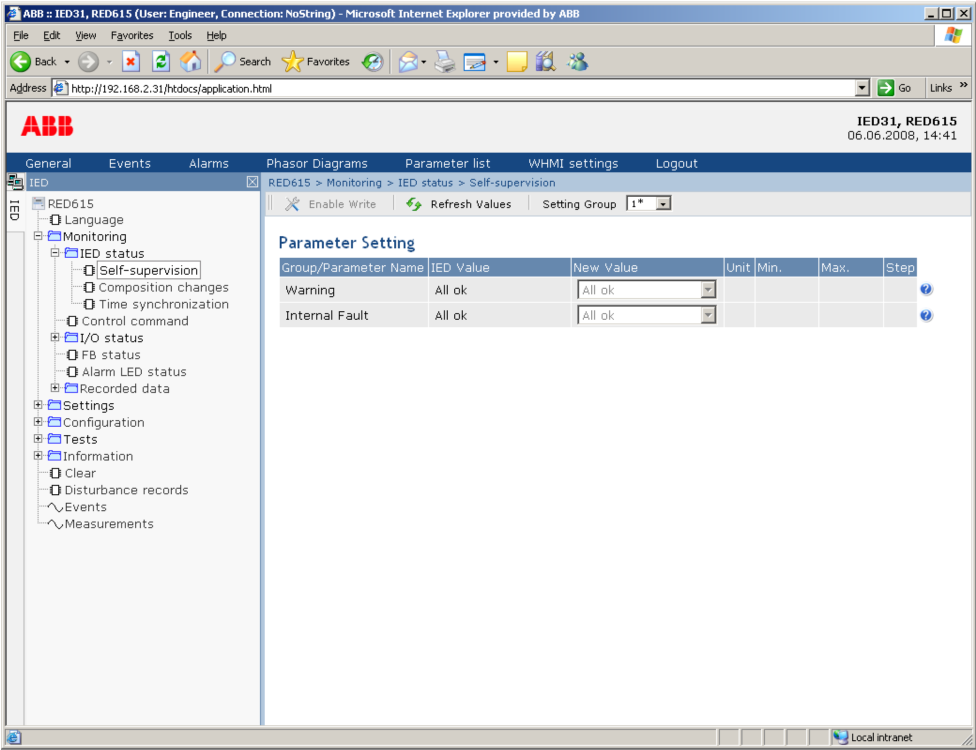


Figure 4: Example view of the WHMI

The WHMI can be accessed:

- Locally by connecting your laptop to the IED via the front communication port.
- Remotely through the Internet or over LAN/WAN.

2.6 Authorization

The user categories have been predefined for the LHMI and the WHMI, each with different rights and default passwords.

The default passwords can be changed with Administrator user rights.

User authorization is disabled by default but WHMI always uses authorization.

Table 3: Predefined user categories

Username	User rights
VIEWER	Read only access
OPERATOR	• Selecting remote or local state with (only locally) • Changing setting groups • Controlling • Clearing alarm and indication LEDs and textual indications
ENGINEER	• Changing settings • Clearing event list • Clearing disturbance records • Changing system settings such as IP address, serial baud rate or disturbance recorder settings • Setting the IED to test mode • Selecting language
ADMINISTRATOR	• All listed above • Changing password

For user authorization for PCM600, see PCM600 documentation.

2.7 Communication

The IED supports two different communication protocols: IEC 61850 and Modbus®. Operational information and controls are available through these protocols. IEC 61850 communication can be used parallel with Modbus®. Modbus® protocol uses either Ethernet or the RS-485 bus.

The IEC 61850 communication implementation supports all monitoring and control functions. Additionally, parameter setting and disturbance file records can be accessed using the IEC 61850-8-1 protocol. Further, the IED can send and receive binary signals from other IEDs (so called horizontal communication) using the IEC 61850-8-1 GOOSE profile, where the highest performance class with a total transmission time of 3 ms is supported. The IED can simultaneously report to five different IEC 61850-8-1 clients.

The IED can support five simultaneous clients. If PCM600 reserves one client connection, only four client connections are left, for example, for IEC 61850 and Modbus.

All communication connectors, except for the front port connector, are placed on integrated optional communication modules. The IED can be connected to Ethernet-based communication systems via the RJ-45 connector (100BASE-TX). If connection to a RS-485 network is required, the 9-pin screw-terminal connector can be used. An ST-type connector for serial communication over fibre optics is available as well. A

direct, dedicated fibre-optic connection is used between the IEDs as a protection communication link. 1300 nm multi-mode or single-mode fibres with LC connectors are used for line differential communication. The LC port in the IED is always the topmost.

Section 3 RED615 variants

3.1 RED615 variant list

The protection and control relay RED615 is mainly intended for MV feeder applications.

The description of the standard configuration covers the full functionality, presenting the functionality, flexibility and external connections of RED615 with the specific configuration as delivered from the factory. The additional BI/O card is not included in the standard configuration.

3.2 Presentation of standard configurations

Functional diagrams

The functional diagrams describe the IED's functionality from the protection, measuring, condition monitoring, disturbance recording, control and interlocking perspective. Diagrams show the default functionality with simple symbol logics forming principle diagrams. The external connections to primary devices are also shown, stating the default connections to measuring transformers. The positive measuring direction of directional protection functions is towards the outgoing feeder.

The functional diagrams are divided into sections which each constitute one functional entity. The external connections are also divided into sections. Only the relevant connections for a particular functional entity are presented in each section.

Protection function blocks are part of the functional diagram. They are identified based on their IEC 61850 name but the IEC based symbol and the ANSI function number are also included. Some function blocks, such as PHHPTOC, are used several times in the configuration. To separate the blocks from each other, the IEC 61850 name, IEC symbol and ANSI function number are appended with a running number, that is an instance number, from one upwards. If the block has no suffix after the IEC or ANSI symbol, the function block has been used, that is, instantiated, only once. The IED’s internal functionality and the external connections are separated with a dashed line presenting the IED’s physical casing.

Signal Matrix Tool

With SMT the user can modify the standard configuration according to the actual needs. The IED is delivered from the factory with default connections described in the functional diagrams for BI's, BO's, function to function connections and alarm LEDs. SMT has a number of different page views, designated as follows:

- Binary input
- Binary output
- Functions.

The functions in different page views are identified by the IEC 61850 names with analogy to the functional diagrams.

3.2.1 Standard configurations

The line differential protection IED RED615 supports the following functions:

Standard configuration functionality	Std. conf. A (DE01)
Protection	
Line differential protection and related measurements, stabilized low-set stage	•
Line differential protection and related measurements, instantaneous high-set stage	•
Three-phase non-directional overcurrent, low-set stage	•
Three-phase non-directional overcurrent, high-set stage, instance 1	•
Three-phase non-directional overcurrent, high-set stage, instance 2	•
Three-phase non-directional overcurrent, instantaneous stage	•
Negative-sequence overcurrent, instance 1	•
Negative-sequence overcurrent, instance 2	•
Circuit breaker failure protection	•
Three-phase inrush current detection	•
Binary signal transfer	•
Control	
Circuit breaker control with interlocking	•
Supervision and Monitoring	
Trip-circuit supervision of two trip circuits	•
Local and remote phase currents (protection co-ordinated)	•
Current circuit supervision	•
Protection communication supervision	•
Measurement	
Transient disturbance recorder	•
Three-phase current measurement	•
Current sequence components	•
Differential current measurement	•
Bias current measurement	•

3.2.2 Connection diagrams

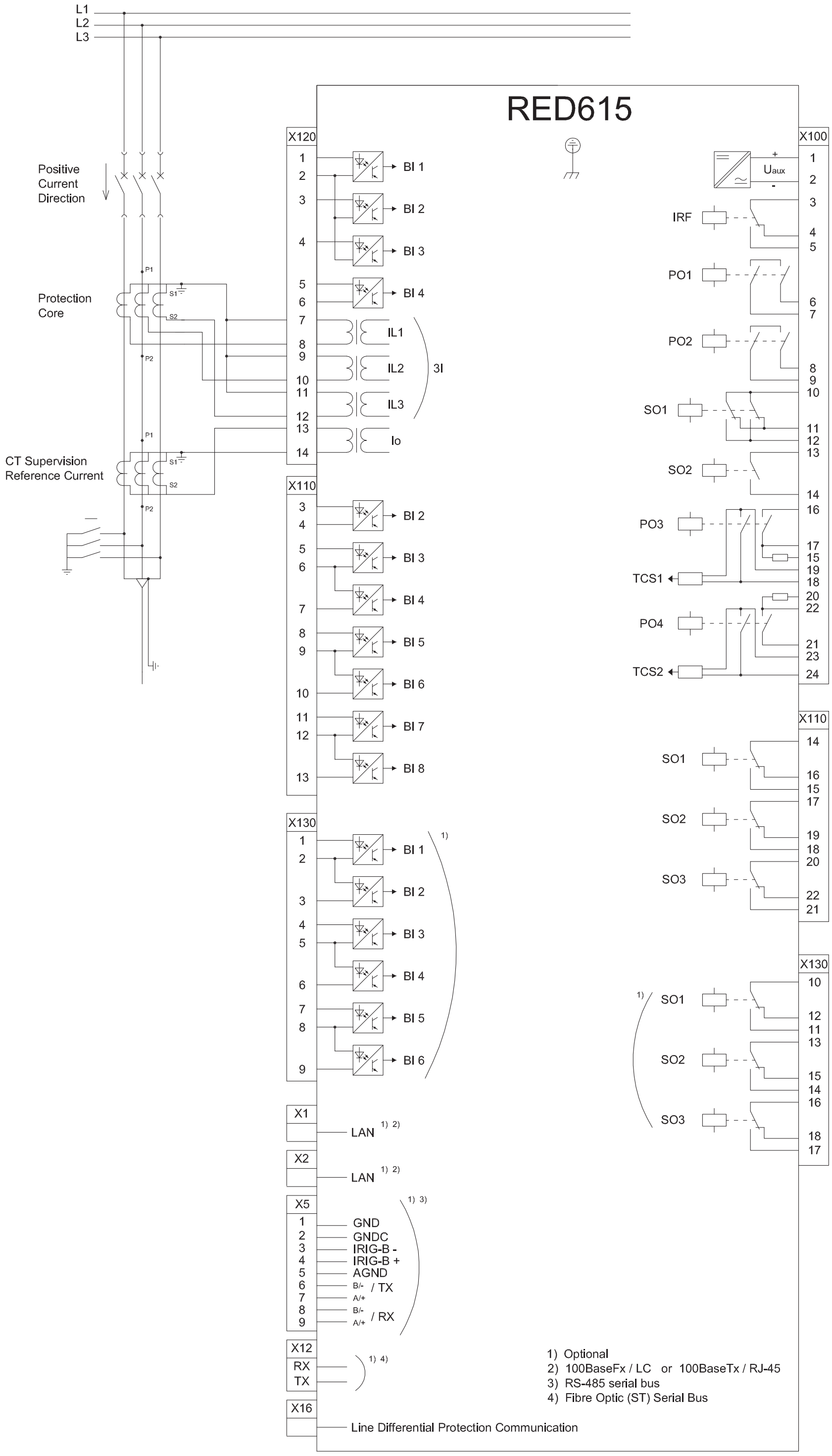


Figure 5: Connection diagram of the RED615 line differential relay with configuration variant A

3.3 Standard configuration A for line current differential protection

3.3.1 Applications

The standard configuration for line current differential protection is mainly intended for cable feeder applications in distribution networks. The IED with this standard configuration is delivered from the factory with default settings and parameters. The end-user flexibility for incoming, outgoing and internal signal designation within the IED enables this configuration to be further adapted to different primary circuit layouts and the related functionality needs by modifying the internal functionality with SMT and PST.

3.3.2 Functions

Table 4: Functions included in the RED615 configuration

Function	IEC 61850	IEC symbol	ANSI symbol
Line differential protection and related measurements, stabilized and inst. stages	LNPLDF1	3Id> 3Id>>	87L
Three-phase non-directional overcurrent, low stage	PHLPTOC1	3I>	51P-1
Three-phase non-directional overcurrent, high stage, instance 1	PHHPTOC1	3I>> (1)	51P-2 (1)
Three-phase non-directional overcurrent, high stage, instance 2	PHHPTOC2	3I>> (2)	51P-2 (2)
Three-phase non-directional overcurrent, inst. stage	PHIPTOC1	3I>>>	50P/51P
Negative-sequence overcurrent protection, instance 1	NSPTOC1	I2> (1)	46 (1)
Negative-sequence overcurrent protection, instance 2	NSPTOC2	I2> (2)	46 (2)
Circuit breaker failure protection	CCBRBRF1	3I>/I_0>BF	51BF/51NBF
Three-phase inrush detector	INRPHAR1	3I2f>	68
Binary signal transfer	BSTGGIO1	BST	BST
Circuit breaker control with interlocking	CBXCBR1	O <-> I	O <-> I
Trip circuit supervision for two trip coils	TCSSCBR1 TCSSCBR2	TCS (1) TCS (2)	TCM (1) TCM (2)
Current circuit supervision	CCRDIF1	CCRDIF	CCRDIF
Protection communication supervision	PCSRTPC1	PCS	PCS
Transient disturbance recorder	RDRE1	-	-
Three-phase current measurement	CMMXU1	3I	3I
Sequence current measurement	CSMSQI1	I_1,I_2,I_0	I_1,I_2,I_0

3.3.2.1 Default I/O connections

Binary input	Default usage	Connector pins
X120-BI1	Blocking input for general use	X120-1,2
X120-BI2	CB Close	X120-3,2
X120-BI3	CB Open	X120-4,2
X120-BI4	Locout reset	X120-5,2

Binary input	Default usage	Connector pins
X110-BI2	External start of Breaker failure protection	X110-3,4
X110-BI3	Setting group change	X110-5,6
X110-BI4	Binary signal transfer input	X110-7,6
X110-BI5	DC Close/Truck In	X110-8,9
X110-BI6	DC Open/Truck Out	X110-10,9
X110-BI7	ES Close	X110-11,12
X110-BI8	ES Open	X110-13,12

Binary output	Default usage	Connector pins
X100-PO1	Close CB	X100-6,7
X100-PO2	Breaker failure backup trip to upstream breaker	X100-8,9
X100-SO1	Line differential protection trip alarm	X100-10,11,(12)
X100-SO2	Protection communication failure or Diff prot not available	X100-13,14
X100-PO3	Open CB/Trip 1	X100-15-19
X100-PO4	Open CB/Trip 2	X100-20-24

Binary output	Default usage	Connector pins
X110-SO1	Start indication	X110-14,15
X110-SO2	Operate indication	X110-17,18
X110-SO3	Binary transfer signal	X110-20,21

LED	Default usage
1	Line differential protection biased stage operate
2	Line differential protection instantaneous stage operate
3	Line differential protection is not available
4	Protection communication failure
5	Current transformer failure detected
6	Phase or negative sequence component over current
7	Breaker failure operate
8	Disturbance recorder triggered
Table continues on next page	

LED	Default usage
9	Trip circuit supervision alarm
10	Binary signal transfer receive
11	Binary signal transfer send

3.3.3 Functional diagrams

The functional diagrams describe the default input, output, alarm LED and function to function connections. The default connections can be viewed with SMT and changed according to the application requirements, if necessary. The analog channels, measurements from CTs and VTs, have fixed connections towards the different function blocks inside the IED's standard configuration.

Exceptions from this rule are the eight analog channels available for the disturbance recorder function. These channels are freely selectable and a part of the disturbance recorder’s parameter settings, thus not included in the SMT functionality.

The analog channels are assigned to different functions as shown in the functional diagrams. The common signal marked with 3I represents the three phase currents. The signal marked with I0 represents the measured residual current, via a sum connection of second CT cores of the phase current transformers.

3.3.3.1 Functional diagrams for protection

The following functional diagrams describe the IED’s protection functionality in detail and according to the factory set default connections in SMT.

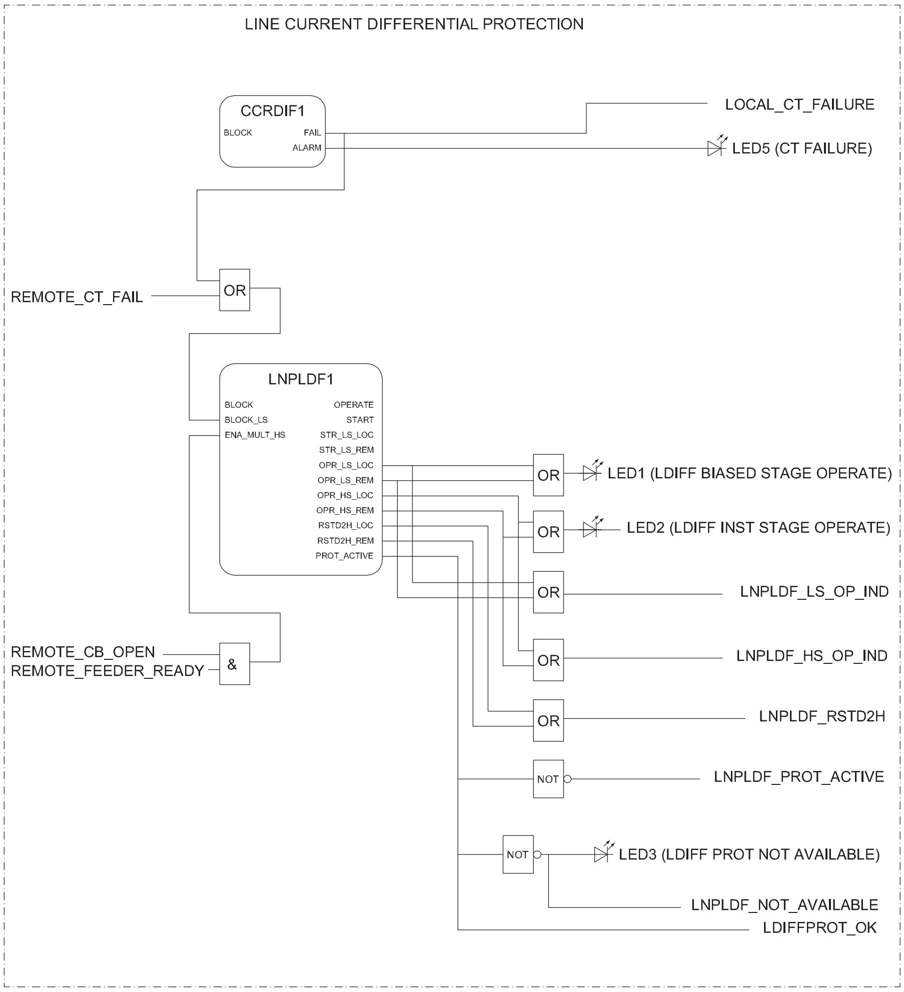


Figure 6: Line differential protection

The line current differential function (LNPLDF) is intended to be the main protection offering exclusive unit protection for the power distribution lines or cables. The stabilized low stage can be blocked if the current transformer failure is detected. The operate value of the instantaneous high stage can be multiplied by a predefined setting if the ENA_MULT input is activated. In this configuration it is activated by the open status information of the remote end circuit breaker, disconnectors and earth switch. The intention of this connection is to lower the setting value of the instantaneous high stage by multiplying with setting *High Op value Mult*, in case of internal fault.

The operate signal is connected to the Master Trip Logics 1 and 2 and also to the alarm LEDs. LED 1 is used for start or operate of stabilized low stage and LED 2 for start or operate of instantaneous high stage indication. The indication of the high or low stage operation is also connected to the output SO1 (X100:10-11-12). The LED 3 is used to indicate if the line differential is not available. This is due to failures in protection communication or the LNPLDF function is set to test mode.

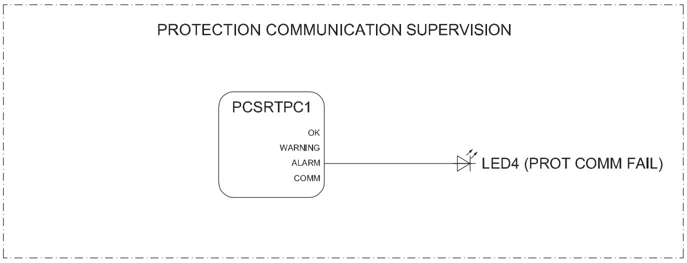


Figure 7: Protection communication supervision

The protection communication supervision function (PCSRTPC) is used in configuration to block the operation of the line differential function. By this way malfunction of the line differential is prevented. Also the activation of binary signal transfer outputs during protection communication failure is blocked. These are done internally without connections in configurations. Anyhow the information of the protection communication supervision alarm is connected to alarm LED4, to disturbance recorder and to signal output SO2 (X100:13-14-15).

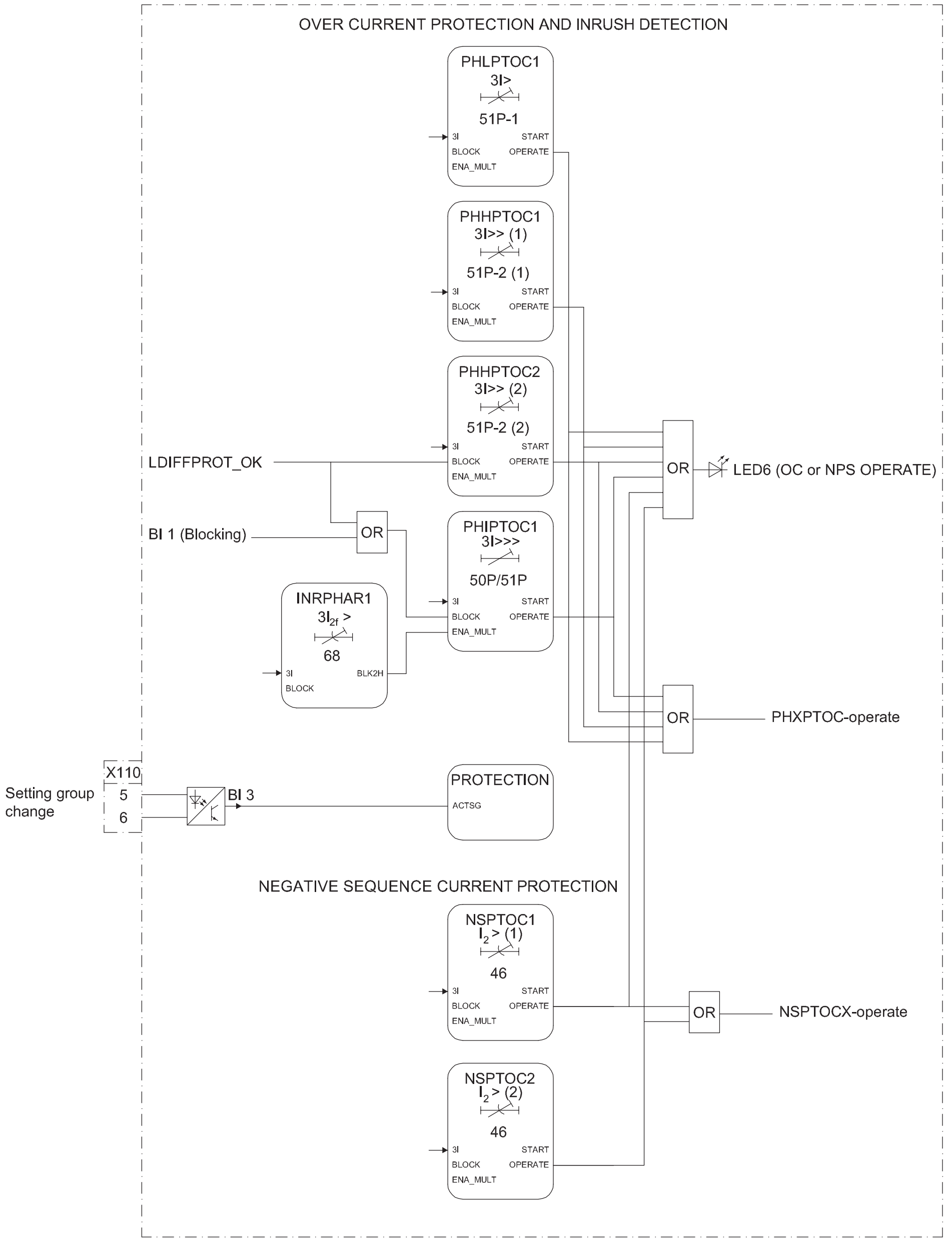


Figure 8: Overcurrent protection

Four overcurrent stages are offered for overcurrent and short-circuit protection. The instantaneous stage (PHIPTOC1) can be blocked by energizing the binary input 1 (X120:1-2). Two negative sequence overcurrent stages (NSPTOC1 and NSPTOC2) are offered for phase unbalance protection. The inrush detection block's (INRPHAR1) output BLK2H caters the possibility to multiply the active settings for instantaneous stage over current protection.

All operate signals are connected to the Master Trip Logics 1 and 2 and also to the alarm LEDs. LED 6 is used for collective overcurrent and negative sequence overcurrent protection operate indication.

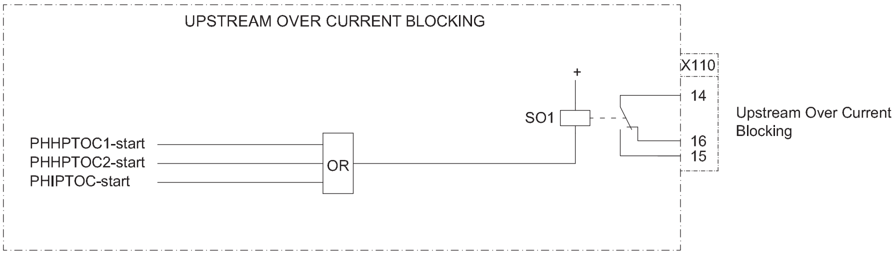


Figure 9: Blocking of the upstream overcurrent relay

The upstream blocking from the start of the over current protection functions is connected to the output SO1 (X110:14-15-16). The purpose of this output is to send a blocking signal to the relevant overcurrent protection stage of the IED at the upstream bay.

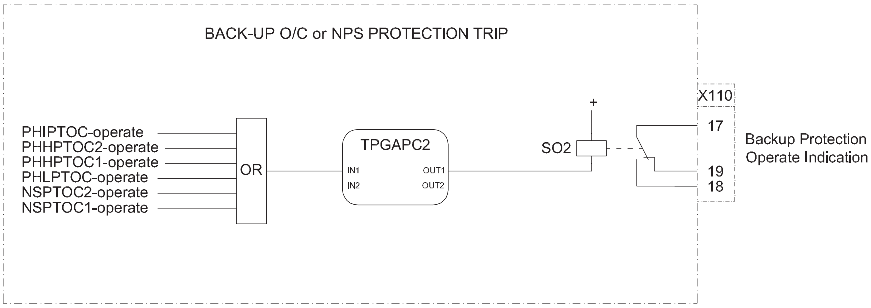


Figure 10: Indication of overcurrent or NPS overcurrent operation

The indication of backup overcurrent protection operation is connected to the output SO2 (X110:20-21-22). It can be used, for example, for external alarm purposes.

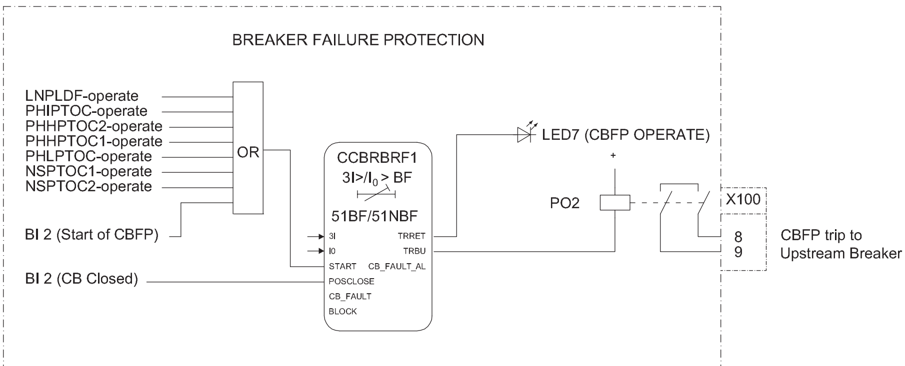


Figure 11: Breaker failure protection

The breaker failure protection (CCBRBRF1) is initiated through the start input by a number of different protection stages in the IED. The breaker failure protection function offers different operating modes associated with circuit breaker position and the measured phase and residual currents. The breaker failure protection has two operating outputs: TRRET and TRBU. The TRRET operate output is used for retripping its own breaker through the Master Trip Logic 2. The TRBU output is used to give a back-up trip to the breaker feeding upstream. For this purpose the TRBU

operate output signal is connected to output PO2 (X100: 8-9). LED 7 is used for backup (TRBU) operate indication.

3.3.3.2 Functional diagrams for disturbance recorder and trip circuit supervision

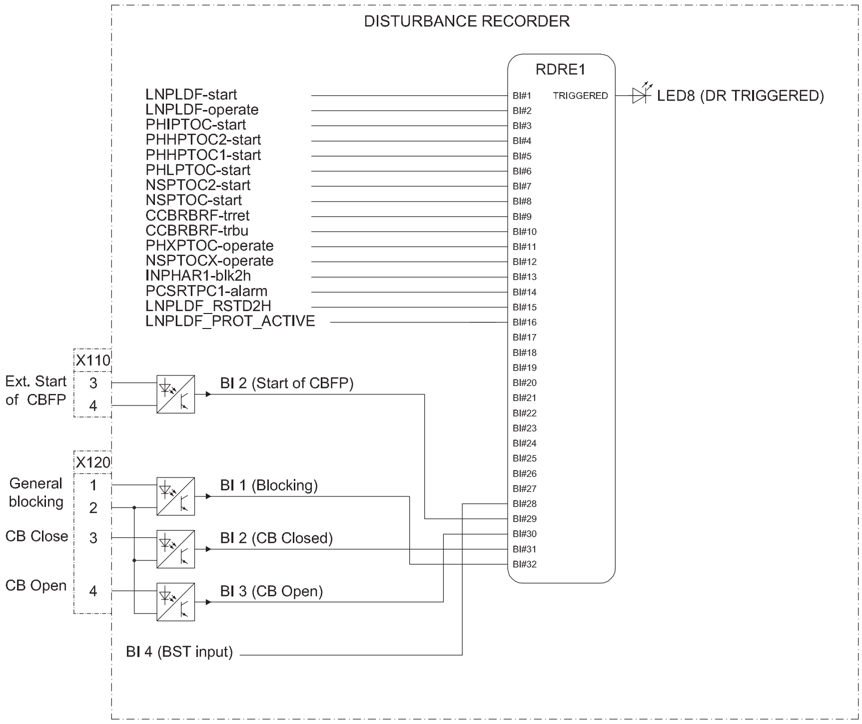


Figure 12: Disturbance recorder

The disturbance recorder has 64 digital inputs of which 32 are connected as a default. All start and operate signals from the protection stages are routed to trigger the disturbance recorder or alternatively only to be recorded by the disturbance recorder depending on the parameter settings. Additionally, the five binary inputs from X120 are also connected.

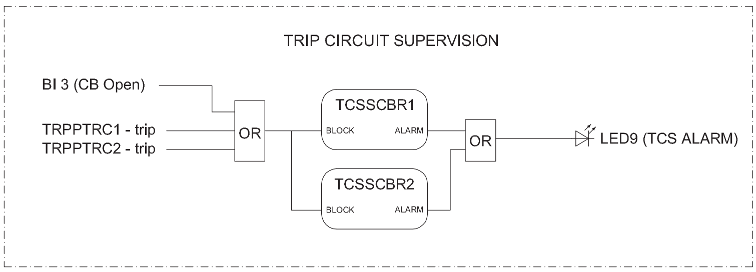


Figure 13: Trip circuit supervision

Two separate TCS functions have been included: TCSSCBR1 for PO3 (X100:16-19) and TCSSCBR2 for PO4 X100:20-23). Both functions are blocked by the Master Trip

Logic and the circuit breaker open signal. The TCS alarm indication is connected to LED 9.

3.3.3.3 Functional diagrams for control, interlocking and measurements

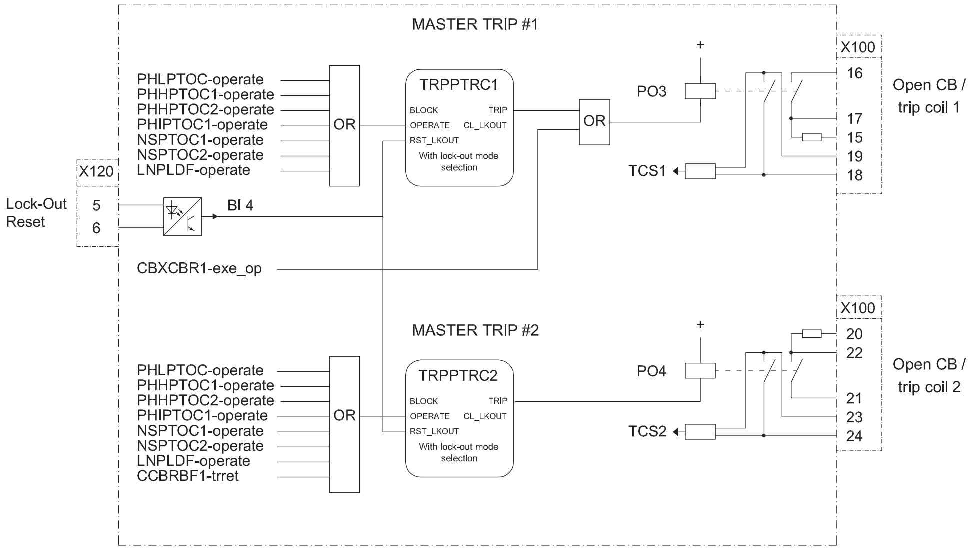


Figure 14: Master trip 1 and 2 functionality

The operate signals from the protections described above are connected to the two trip output contacts PO3 (X100:16-19) and PO4 (X100:20-23) via the corresponding Master Trip Logics TRPPTRC1 and TRPPTRC2. The open control commands to the circuit breaker from local or remote CBXCR1-exe_op is connected directly to the output PO3 (X100:16-19).

The TRPPTRC1 and 2 blocks provide the lockout/latching function, event generation and the trip signal duration setting. If the lockout operation mode is selected, one binary input can be re-assigned to the RST_LKOUT input of the Master Trip Logics to enable external reset via a push-button.

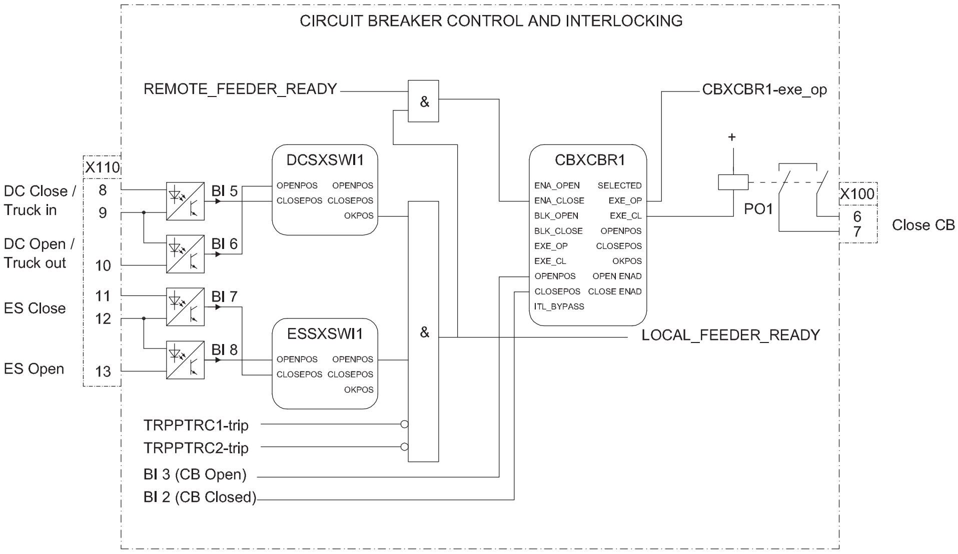


Figure 15: Circuit breaker control and interlocking

The ENA_CLOSE input, that is enable the close of circuit breaker, in the breaker control function block CBXBR is a combination of the status of the Master Trip Logics, disconnector and earthing switch position indications and remote feeder position indications. Master trip logic, disconnector and earthing switch status are local feeder ready information to be sent for remote end. Open operation is always enabled.

If the ENA_CLOSE signal is completely removed from the breaker control function block CBXBR with SMT, the function assumes that the breaker close commands are allowed continuously.

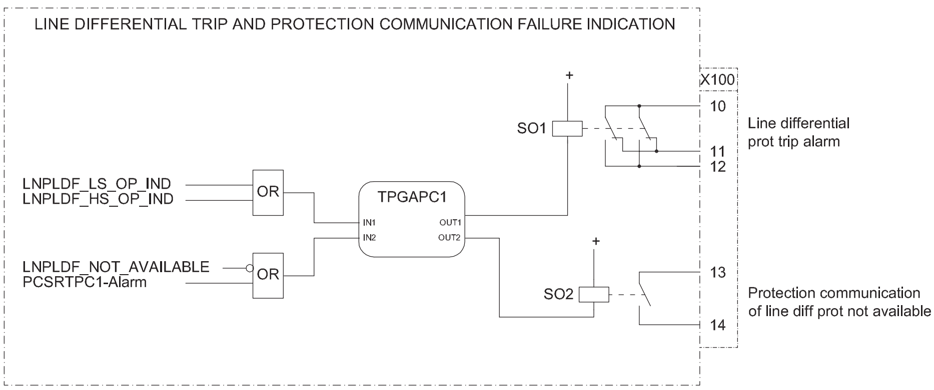


Figure 16: Line differential trip and protection communication failure indication

The signal outputs from the IED are connected to give dedicated information on:

- start of any protection function SO1 (X100:10-12)
- operation (trip) of any protection function SO2 (X100:13-15) The TRGAPC1 is a timer and used for setting the minimum pulse length for the outputs.

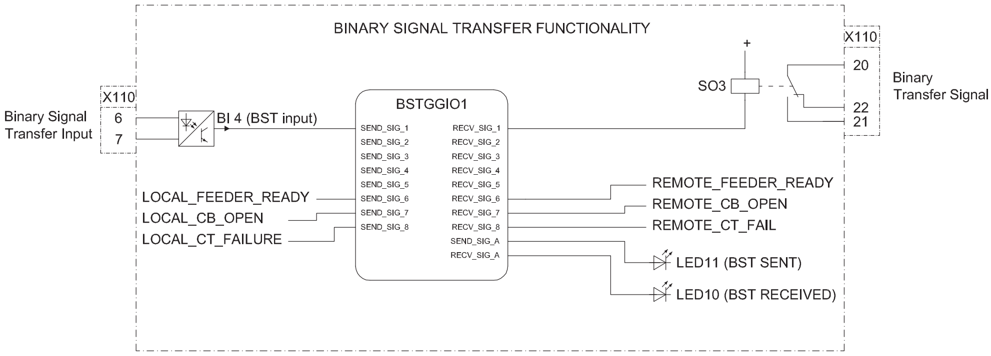


Figure 17: Binary signal transfer functionality

The binary signal transfer function (BSTGGIO) is used for changing any binary information which can be used e.g. in protection schemes, interlocking, alarms etc. There are eight separate inputs and corresponding outputs available.

In this configuration one physical input BI3 (X110:6-7) is connected to the binary signal transfer channel one. Local feeder ready and local CB open information are connected to input 6 and 7. These are interlocking information from control logic. The information of detected current transformer fault is connected to input 8.

As a consequence of sending interlocking information to remote end also receiving of same information locally is needed. Therefore remote feeder ready, remote CB open and remote CT failure are connected to binary signal transfer function outputs. All binary signal transfer outputs are connected to output SO3 (X110:20-21-22).

The receive and send information are connected to alarm LEDs 10 and 11.

Section 4 Basic functions

4.1 General parameters

Table 5: Analog channel settings, phase currents

Parameter	Values (Range)	Unit	Step	Default	Description
Secondary current	1=0.2A 2=1A 3=5A			2=1A	Rated recondary current
Primary current	1.0...6000.0	A	0.1	100.0	Rated primary current
Amplitude corr. A	0.900...1.100		0.001	1.000	Phase A amplitude correction factor
Amplitude corr. B	0.900...1.100		0.001	1.000	Phase B amplitude correction factor
Amplitude corr. C	0.900...1.100		0.001	1.000	Phase C amplitude correction factor

Table 6: Analog channel settings, residual current

Parameter	Values (Range)	Unit	Step	Default	Description
Secondary current	1=0.2A 2=1A 3=5A			2=1A	Secondary current
Primary current	1.0...6000.0	A	0.1	100.0	Primary current
Amplitude corr.	0.900...1.100		0.001	1.000	Amplitude correction

Table 7: Alarm LED input signals

Name	Type	Default	Description
Alarm LED 1	BOOLEAN	0=False	Status of Alarm LED 1
Alarm LED 2	BOOLEAN	0=False	Status of Alarm LED 2
Alarm LED 3	BOOLEAN	0=False	Status of Alarm LED 3
Alarm LED 4	BOOLEAN	0=False	Status of Alarm LED 4
Alarm LED 5	BOOLEAN	0=False	Status of Alarm LED 5
Alarm LED 6	BOOLEAN	0=False	Status of Alarm LED 6
Alarm LED 7	BOOLEAN	0=False	Status of Alarm LED 7
Alarm LED 8	BOOLEAN	0=False	Status of Alarm LED 8

Table continues on next page

Name	Type	Default	Description
Alarm LED 9	BOOLEAN	0=False	Status of Alarm LED 9
Alarm LED 10	BOOLEAN	0=False	Status of Alarm LED 10
Alarm LED 11	BOOLEAN	0=False	Status of Alarm LED 11

Table 8: Alarm LED settings

Parameter	Values (Range)	Unit	Step	Default	Description
Alarm LED mode	0=Follow-S[1)] 1=Follow-F[2)] 2=Latched-S[3)] 3=LatchedAck-F-S[4)]			0=Follow-S	Alarm mode for LED 1
Description				Alarm LEDs LED 1	Description of alarm
Alarm LED mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for LED 2
Description				Alarm LEDs LED 2	Description of alarm
Alarm LED mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for LED 3
Description				Alarm LEDs LED 3	Description of alarm
Alarm LED mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for LED 4
Description				Alarm LEDs LED 4	Description of alarm
Alarm LED mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for LED 5
Description				Alarm LEDs LED 5	Description of alarm
Alarm LED mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for LED 6
Description				Alarm LEDs LED 6	Description of alarm
Alarm LED mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for LED 7
Description				Alarm LEDs LED 7	Description of alarm
Alarm LED mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for LED 8
Description				Alarm LEDs LED 8	Description of alarm
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
Alarm LED mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for LED 9
Description				Alarm LEDs LED 9	Description of alarm
Alarm LED mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for LED 10
Description				Alarm LEDs LED 10	Description of alarm
Alarm LED mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for LED 11
Description				Alarm LEDs LED 11	Description of alarm

1) Non-latched mode
2) Non-latched blinking mode
3) Latched mode
4) Latched blinking mode

Table 9: Authorization settings

Parameter	Values (Range)	Unit	Step	Default	Description
Local override	0=False[1)] 1=True[2)]			1=True	Disable authority
Remote override	0=False[3)] 1=True[4)]			1=True	Disable authority
Local viewer				0	Set password
Local operator				0	Set password
Local engineer				0	Set password
Local admin				0	Set password
Remote viewer				0	Set password
Remote operator				0	Set password
Remote engineer				0	Set password
Remote admin				0	Set password

1) Authorization override is disabled, LHMI password must be entered.
2) Authorization override is enabled, LHMI password is not asked.
3) Authorization override is disabled, communication tools ask password to enter the IED.
4) Authorization override is enabled, communication tools do not need password to enter the IED, except for WHMI which always requires it.

Table 10: Binary input settings

Parameter	Values (Range)	Unit	Step	Default	Description
Threshold voltage	18...176	Vdc	2	18	Digital input threshold voltage
Input osc. level	2...50		1	30	Digital input oscillation suppression threshold
Input osc. hyst	2...50		1	10	Digital input oscillation suppression hysteresis

Table 11: Ethernet front port settings

Parameter	Values (Range)	Unit	Step	Default	Description
IP address				192.168.000.254	IP address for front port (fixed)
Mac address				XX-XX-XX-XX-XX-XX	Mac address for front port

Table 12: Ethernet rear port settings

Parameter	Values (Range)	Unit	Step	Default	Description
IP address				192.168.2.10	IP address for rear port(s)
Subnet mask				255.255.255.0	Subnet mask for rear port(s)
Default gateway				192.168.2.1	Default gateway for rear port(s)
Mac address				XX-XX-XX-XX-XX-XX	Mac address for rear port(s)

Table 13: General system settings

Parameter	Values (Range)	Unit	Step	Default	Description
Rated frequency	1=50Hz 2=60Hz			1=50Hz	Rated frequency of the network
Phase rotation	1=ABC 2=ACB			1=ABC	Phase rotation order
Blocking mode	1=Freeze timer 2=Block all 3=Block OPERATE output			1=Freeze timer	Behaviour for function BLOCK inputs
Bay name				RED615	Bay name in system

Table 14: HMI settings

Parameter	Values (Range)	Unit	Step	Default	Description
FB naming convention	1=IEC61850 2=IEC61617 3=IEC-ANSI			1=IEC61850	FB naming convention used in IED
Default view	1=Measurements 2=Main menu			1=Measurements	LHMI default view
Backlight timeout	10...3600	s	1	180	LHMI backlight timeout
Web HMI mode	1=Active read only 2=Active 3=Disabled			3=Disabled	Web HMI functionality
Web HMI timeout	120...3600	s	1	180	Web HMI login timeout

Table 15: MODBUS settings

Parameter	Values (Range)	Unit	Step	Default	Description
InOv	0=False 1=True			0=False	Modbus Internal Overflow: TRUE-System level overflow occured (indication only)
Serial port 1	0=Not in use 1=COM 1 2=COM 2			1=COM 1	COM port for Serial interface 1
Address 1	1...255			1	Modbus unit address on Serial interface 1
Link mode 1	1=RTU 2=ASCII			1=RTU	Modbus link mode on Serial interface 1
Start delay 1	0...20	char		4	Start frame delay in chars on Serial interface 1
End delay 1	0...20	char		4	End frame delay in chars on Serial interface 1
Serial port 2	0=Not in use 1=COM 1 2=COM 2			0=Not in use	COM port for Serial interface 2
Address 2	1...255			2	Modbus unit address on Serial interface 2
Link mode 2	1=RTU 2=ASCII			1=RTU	Modbus link mode on Serial interface 2
Start delay 2	0...20	char		4	Start frame delay in chars on Serial interface 2
End delay 2	0...20	char		4	End frame delay in chars on Serial interface 2
MaxTCPClients	0...5			5	Maximum number of Modbus TCP/IP clients
TCPWriteAuthority	0=No clients 1=Reg. clients 2=All clients			2=All clients	Write authority setting for Modbus TCP/IP clients
EventID	0=Address 1=UID			0=Address	Event ID selection
TimeFormat	0=UTC 1=Local			1=Local	Time format for Modbus time stamps
ClientIP1				000.000.000.000	Modbus Registered Client 1
ClientIP2				000.000.000.000	Modbus Registered Client 2
ClientIP3				000.000.000.000	Modbus Registered Client 3
ClientIP4				000.000.000.000	Modbus Registered Client 4

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
ClientIP5				000.000.000.000	Modbus Registered Client 5
CtlStructPWd1				****	Password for Modbus control struct 1
CtlStructPWd2				****	Password for Modbus control struct 2
CtlStructPWd3				****	Password for Modbus control struct 3
CtlStructPWd4				****	Password for Modbus control struct 4
CtlStructPWd5				****	Password for Modbus control struct 5
CtlStructPWd6				****	Password for Modbus control struct 6
CtlStructPWd7				****	Password for Modbus control struct 7
CtlStructPWd8				****	Password for Modbus control struct 8

Table 16: Serial communication settings

Parameter	Values (Range)	Unit	Step	Default	Description
Fiber mode	0=No fiber 1=Fiber light ON loop 2=Fiber light OFF loop 3=Fiber light ON star 4=Fiber light OFF star			0=No fiber	Fiber mode for COM1
Serial mode	1=RS485 2Wire 2=RS485 4Wire			1=RS485 2Wire	Serial mode for COM1
CTS delay	0...60000			0	CTS delay for COM1
RTS delay	0...60000			0	RTS delay for COM1
Baudrate	1=300 2=600 3=1200 4=2400 5=4800 6=9600 7=19200 8=38400 9=57600 10=115200			6=9600	Baudrate for COM1
Parity	0=none 1=odd 2=even			2=even	Parity for COM1

Table 17: Time settings

Parameter	Values (Range)	Unit	Step	Default	Description
Date				0	Date
Time				0	Time
Time format	1=24H:MM:SS:MS 2=12H:MM:SS:MS			1=24H:MM:SS:MS	Time format

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Date format	1=DD.MM.YYYY 2=DD/MM/YYYY 3=DD-MM-YYYY 4=MM.DD.YYYY 5=MM/DD/YYYY 6=YYYY-MM-DD 7=YYYY-DD-MM 8=YYYY/DD/MM			1=DD.MM.YYYY	Date format
Local time offset	-720...720	min		0	Local time offset in minutes
Synch source	0=None 1=SNTP 2=Modbus 5=IRIG-B 8=Line differential			1=SNTP	Time synchronization source
IP SNTP primary				010.058.125.165	IP address for SNTP primary server
IP SNTP secondary				192.168.002.165	IP address for SNTP secondary server
DST on time				02:00	Daylight savings time on, time (hh:mm)
DST on date				01.05.	Daylight savings time on, date (dd:mm)
DST on day	0=Not in use 1=Mon 2=Tue 3=Wed 4=Thu 5=Fri 6=Sat 7=Sun			0=Not in use	Daylight savings time on, day of week
DST offset	-720...720	min		60	Daylight savings time offset, in minutes
DST off time				02:00	Daylight savings time off, time (hh:mm)
DST off date				25.09.	Daylight savings time off, date (dd:mm)
DST off day	0=Not in use 1=Mon 2=Tue 3=Wed 4=Thu 5=Fri 6=Sat 7=Sun			0=Not in use	Daylight savings time off, day of week

Table 18: X100 PSM binary output signals

Name	Type	Default	Description
X100-PO1	BOOLEAN	0=False	Connectors 6-7
X100-PO2	BOOLEAN	0=False	Connectors 8-9
X100-SO1	BOOLEAN	0=False	Connectors 10c-11nc-12no
X100-SO2	BOOLEAN	0=False	Connectors 13c-14no
X100-PO3	BOOLEAN	0=False	Connectors 15-17/18-19
X100-PO4	BOOLEAN	0=False	Connectors 20-22/23-24

Table 19: X110 BIO binary output signals

Name	Type	Default	Description
X110-SO1	BOOLEAN	0=False	Connectors 14c-15no-16nc
X110-SO2	BOOLEAN	0=False	Connectors 17c-18no-19nc
X110-SO3	BOOLEAN	0=False	Connectors 20c-21no-22nc

Table 20: X110 BIO binary input signals

Name	Type	Description
X110-Input 2	BOOLEAN	Connectors 3-4
X110-Input 3	BOOLEAN	Connectors 5-6c
X110-Input 4	BOOLEAN	Connectors 7-6c
X110-Input 5	BOOLEAN	Connectors 8-9c
X110-Input 6	BOOLEAN	Connectors 10-9c
X110-Input 7	BOOLEAN	Connectors 11-12c
X110-Input 8	BOOLEAN	Connectors 13-12c

Table 21: X110 BIO binary input settings

Parameter	Values (Range)	Unit	Step	Default	Description
Input 2 filter time	1...1000	ms		5	Connectors 3-4
Input 3 filter time	1...1000	ms		5	Connectors 5-6c
Input 4 filter time	1...1000	ms		5	Connectors 7-6c
Input 5 filter time	1...1000	ms		5	Connectors 8-9c
Input 6 filter time	1...1000	ms		5	Connectors 10-9c
Input 7 filter time	1...1000	ms		5	Connectors 11-12c
Input 8 filter time	1...1000	ms		5	Connectors 13-12c
Input 2 inversion	0=False 1=True			0=False	Connectors 3-4
Input 3 inversion	0=False 1=True			0=False	Connectors 5-6c
Input 4 inversion	0=False 1=True			0=False	Connectors 7-6c
Input 5 inversion	0=False 1=True			0=False	Connectors 8-9c
Input 6 inversion	0=False 1=True			0=False	Connectors 10-9c
Input 7 inversion	0=False 1=True			0=False	Connectors 11-12c
Input 8 inversion	0=False 1=True			0=False	Connectors 13-12c

Table 22: X120 AIM binary input signals

Name	Type	Description
X120-Input 1	BOOLEAN	Connectors 1-2c
X120-Input 2	BOOLEAN	Connectors 3-2c
X120-Input 3	BOOLEAN	Connectors 4-2c
X120-Input 4	BOOLEAN	Connectors 5-6

Table 23: X120 AIM binary input settings

Parameter	Values (Range)	Unit	Step	Default	Description
Input 1 filter time	1...1000	ms		5	Connectors 1-2c
Input 2 filter time	1...1000	ms		5	Connectors 3-2c
Input 3 filter time	1...1000	ms		5	Connectors 4-2c
Input 4 filter time	1...1000	ms		5	Connectors 5-6
Input 1 inversion	0=False 1=True			0=False	Connectors 1-2c
Input 2 inversion	0=False 1=True			0=False	Connectors 3-2c
Input 3 inversion	0=False 1=True			0=False	Connectors 4-2c
Input 4 inversion	0=False 1=True			0=False	Connectors 5-6

4.2 Self-supervision

The IED's extensive self-supervision system continuously supervises the software and the electronics. It handles run-time fault situations and informs the user about the existing faults via the LHMI and the communication.

There are two types of fault indications.

- Internal faults
- Warnings

4.2.1 Internal faults

Internal fault indications have the highest priority on the LHMI. None of the other LHMI indications can override the internal fault indication.

An indication about the fault is shown as a message on the LHMI. The text `Internal Fault` with an additional text message, a code, date and time, is shown to indicate the fault type.

Different actions are taken depending on the severity of the fault. The IED tries to eliminate the fault by restarting. After the fault is found to be permanent, the IED stays in internal fault mode. All other output contacts are released and locked for the internal fault. The IED continues to perform internal tests during the fault situation.

The internal fault code indicates the type of internal IED fault. When a fault appears, document the code and state it when ordering the service.

Table 24: Internal fault indications and codes

Fault indication	Fault code	Additional information
Internal Fault System error	2	An internal system error has occurred.
Internal Fault File system error	7	A file system error has occurred.
Internal Fault Test	8	Internal fault test activated manually by the user.
Internal Fault SW watchdog error	10	Watchdog reset has occurred too many times within an hour.
Internal Fault SO-relay(s),X100	43	Faulty Signal Output relay(s) in card located in slot X100.
Internal Fault SO-relay(s),X110	44	Faulty Signal Output relay(s) in card located in slot X110.
Internal Fault SO-relay(s),X130	46	Faulty Signal Output relay(s) in card located in slot X130.
Internal Fault PO-relay(s),X100	53	Faulty Power Output relay(s) in card located in slot X100.
Internal Fault PO-relay(s),X110	54	Faulty Power Output relay(s) in card located in slot X110.
Internal Fault PO-relay(s),X130	56	Faulty Power Output relay(s) in card located in slot X130.
Internal Fault Light sensor error	57	Faulty ARC light sensor input(s).
Internal Fault Conf. error,X000	62	Card in slot X000 is wrong type.
Internal Fault Conf. error,X100	63	Card in slot X100 is wrong type or does not belong to the original composition.
Internal Fault Conf. error,X110	64	Card in slot X110 is wrong type, is missing or does not belong to the original composition.
Internal Fault Conf. error,X120	65	Card in slot X120 is wrong type, is missing or does not belong to the original composition.
Internal Fault Conf. error,X130	66	Card in slot X130 is wrong type, is missing or does not belong to the original composition.
Internal Fault Card error,X000	72	Card in slot X000 is faulty.

Table continues on next page

Fault indication	Fault code	Additional information
Internal Fault Card error,X100	73	Card in slot X100 is faulty.
Internal Fault Card error,X110	74	Card in slot X110 is faulty.
Internal Fault Card error,X120	75	Card in slot X120 is faulty.
Internal Fault Card error,X130	76	Card in slot X130 is faulty.
Internal Fault LHMI module	79	LHMI module is faulty. The fault indication may not be seen on the LHMI during the fault.
Internal Fault RAM error	80	Error in the RAM memory on the CPU card.
Internal Fault ROM error	81	Error in the ROM memory on the CPU card.
Internal Fault EEPROM error	82	Error in the EEPROM memory on the CPU card.
Internal Fault FPGA error	83	Error in the FPGA on the CPU card.
Internal Fault RTC error	84	Error in the RTC on the CPU card.

4.2.2 Warnings

A fault indication message, which includes text `Warning` with additional text, a code, date and time, is shown on the LHMI to indicate the fault type. If more than one type of fault occur at the same time, indication of the latest fault appears on the LCD. The fault indication message can be manually cleared.

When a fault appears, the fault indication message is to be recorded and stated when ordering service.

Table 25: Warning indications and codes

Warning indication	Warning code	Additional information
Warning Watchdog reset	10	A watchdog reset has occurred.
Warning Power down det.	11	The auxiliary supply voltage has dropped too low.
Warning IEC61850 error	20	Error when building the IEC 61850 data model.
Warning Modbus error	21	Error in the Modbus communication.
Warning DNP3 error	22	Error in the DNP3 communication.
Warning Dataset error	24	Error in the Data set(s).
Warning Report cont. error	25	Error in the Report control block(s).
Table continues on next page		

Warning indication	Warning code	Additional information
Warning GOOSE contr. error	26	Error in the GOOSE control block(s).
Warning SCL config error	27	Error in the SCL configuration file or the file is missing.
Warning Logic error	28	Too many connections in the configuration.
Warning SMT logic error	29	Error in the SMT connections.
Warning GOOSE input error	30	Error in the GOOSE connections.
Warning GOOSE rec. error	32	Error in the GOOSE message receiving.
Warning AFL error	33	Analog channel configuration error.
Warning Unack card comp.	40	A new composition has not been acknowledged/accepted.
Warning Protection comm.	50	Error in protection communication.
Warning ARC1 cont. light	85	A continuous light has been detected on the ARC light input 1.
Warning ARC2 cont. light	86	A continuous light has been detected on the ARC light input 2.
Warning ARC3 cont. light	87	A continuous light has been detected on the ARC light input 3.

4.3 Time synchronization

The IED uses SNTP server or GPS controlled IRIG-B time code generator to update its real time clock. The time stamp is used for synchronizing the events.

The IED can use one of two SNTP servers, the primary server or the secondary server. The primary server is mainly in use, whereas the secondary server is used if the primary server cannot be reached. While using the secondary SNTP server, the IED tries to switch to the primary server at every third SNTP request attempt.

If both SNTP servers are offline, the event time stamps have the time invalid status. The time is requested from the SNTP server every 60 seconds.

If the Modbus RTU/ASCII protocol is used, the time synchronization can be received from Modbus master instead of SNTP. When Modbus TCP is used, SNTP time synchronization should be used for better synchronization accuracy.

IRIG-B time synchronization requires the IRIG-B format B000/B001 with IEEE-1344 extensions. The synchronization time can be either UTC time or local

time. As no reboot is necessary, the time synchronization starts immediately after the IRIG-B sync source is selected and the IRIG-B signal source is connected.

ABB has tested the IRIG-B with the following clock masters:

- Tekron TTM01 GPS clock with IRIG-B output
- Meinberg TCG511 controlled by GPS167
- Datum ET6000L.

IRIG-B time synchronization requires a COM card with an IRIG-B input.

The time synchronization messages can be received from the other line end IED within the protection telegrams. The IED begins to synchronize its real-time clock with the remote end IEDs time if the Line differential time synchronization source is selected. This does not affect the protection synchronization used in the line differential protection or the selection of the remote end IEDs time synchronization method.

4.4 Parameter setting groups

There are four IED variant specific setting groups. For each setting group the parameter setting can be made independently.

The active setting group (1...4) can be changed by parameter or via binary input, if a binary input is enabled for it.

To enable active setting group changing via binary input, connect any of the (free) binary inputs to SGCB-block input named Protection (0) ActSG using PCM600 Signal Matrix Tool.

Table 26: Active setting group binary input state

BI state	Active setting group
OFF	1
ON	2

The active setting group defined by parameter is overridden when a binary input is enabled for changing the active setting group.

Table 27: Settings

Parameter	Setting	Value	Default	Description	Access rights
Setting group	Active group	1...4	1	Selected active group	RWRW

All the parameters are not included in these setting groups, for example, non-setting group parameters. Those parameters are presented in connection to application functions.

Section 5 Protection functions

5.1 Line differential protection LNPLDF

5.1.1 Identification

Table 28: Function identification

IEC 61850 identification:	LNPLDF
IEC 60617 identification:	3dI>, 3dI>>
ANSI/IEEE C37.2 device number:	87L

5.1.2 Functionality

The phase segregated line differential protection LNPLDF is used as feeder differential protection for the distribution network lines and cables. LNPLDF includes low, stabilized and high, non-stabilized stages.

The stabilized low stage provides a fast clearance of faults while remaining stable with high currents passing through the protected zone increasing errors on current measuring. Second harmonic restraint insures that the low stage does not operate due to the startup of the tapped transformer. The high stage provides a very fast clearance of severe faults with a high differential current regardless of their harmonics.

The operating time characteristic for the low stage can be selected to be either definite time (DT) or inverse definite time (IDMT). The direct inter-trip ensures both ends are always operated, even without local criteria.

5.1.3 Application

LNPLDF is designed for the differential protection of overhead line and cable feeders in a distribution network. LNPLDF provides absolute selectivity and fast operating times as unit protection also in short lines where distance protection cannot be applied.

LNPLDF provides selective protection for radial, looped and meshed network topologies and can be used in isolated neutral networks, resistance earthed networks, compensated (impedance earthed) networks and solidly earthed networks. In a typical network configuration where the line differential protection scheme is applied, the protected zone, that is, the line or cable, is fed from two directions.

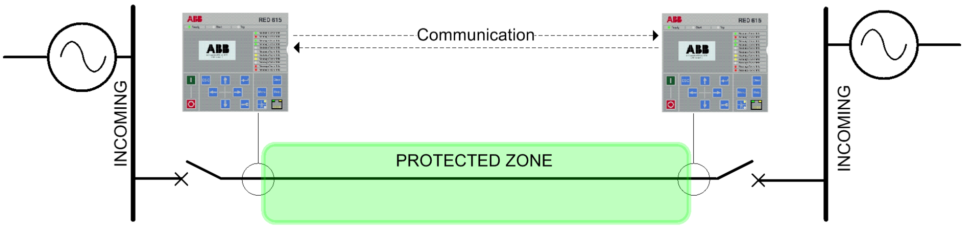


Figure 18: Line protection with phase segregated line differential IEDs

LNPLDF can be utilized for various types of network configurations or topologies. Case A shows the protection of a ring-type distribution network. The network is also used in the closed ring mode. LNPLDF is used as the main protection for different sections of the feeder. In case B, the interconnection of two substations is done with parallel lines and each line is protected with the line differential protection. In case C, the connection line to mid scale power generation (typical size around 10 - 50MVA) is protected with the line differential function. In case D, the connection between two substations and a small distribution transformer is located at the tapped load. The usage of LNPLDF is not limited to these applications.

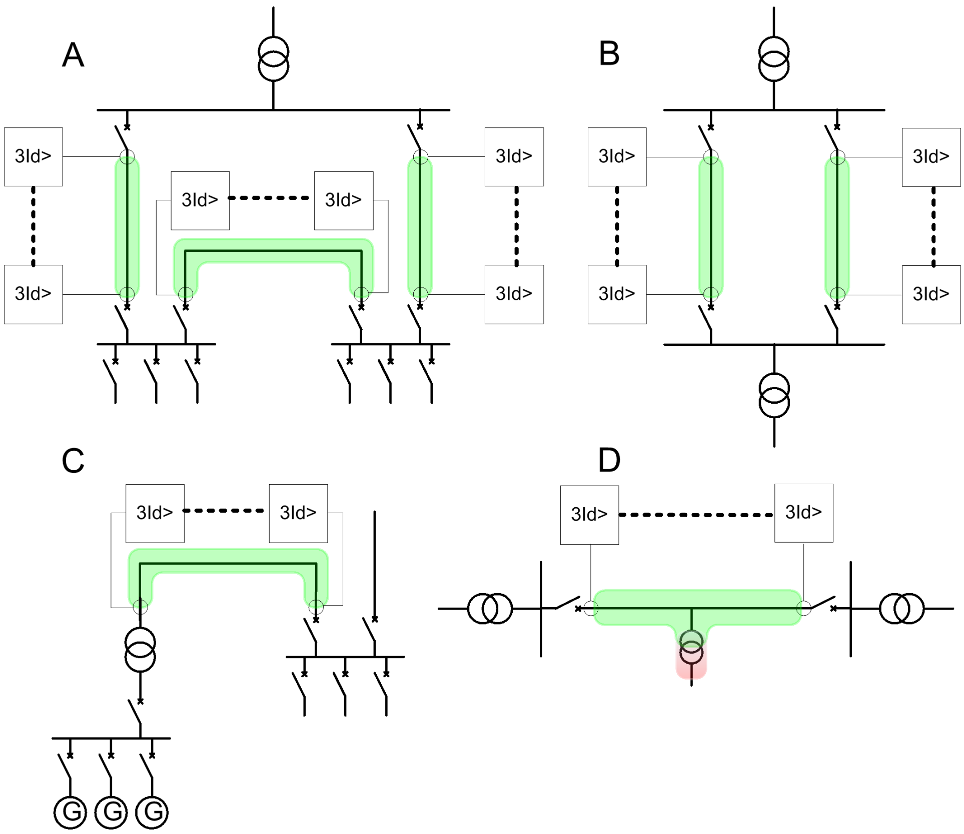


Figure 19: Line differential applications

Communication supervision

A typical line differential protection application includes LNPLDF as main protection. Backup over current functions are needed in case of a protection communication failure. When the communication supervision function detects a failure in the communication between the protective units, the safe operation of the line is still guaranteed by blocking the line differential protection and unblocking the over current functions.

When a communication failure is detected, the protection communication supervision function issues block for the LNPLDF line differential protection and unblock for the instantaneous and high stages (instance 2) of the over current protection. These are used to give backup protection for the remote end feeder protection IED. Although there can be a situation where the selectivity is weaker than usually, the protection should still be available for the system.

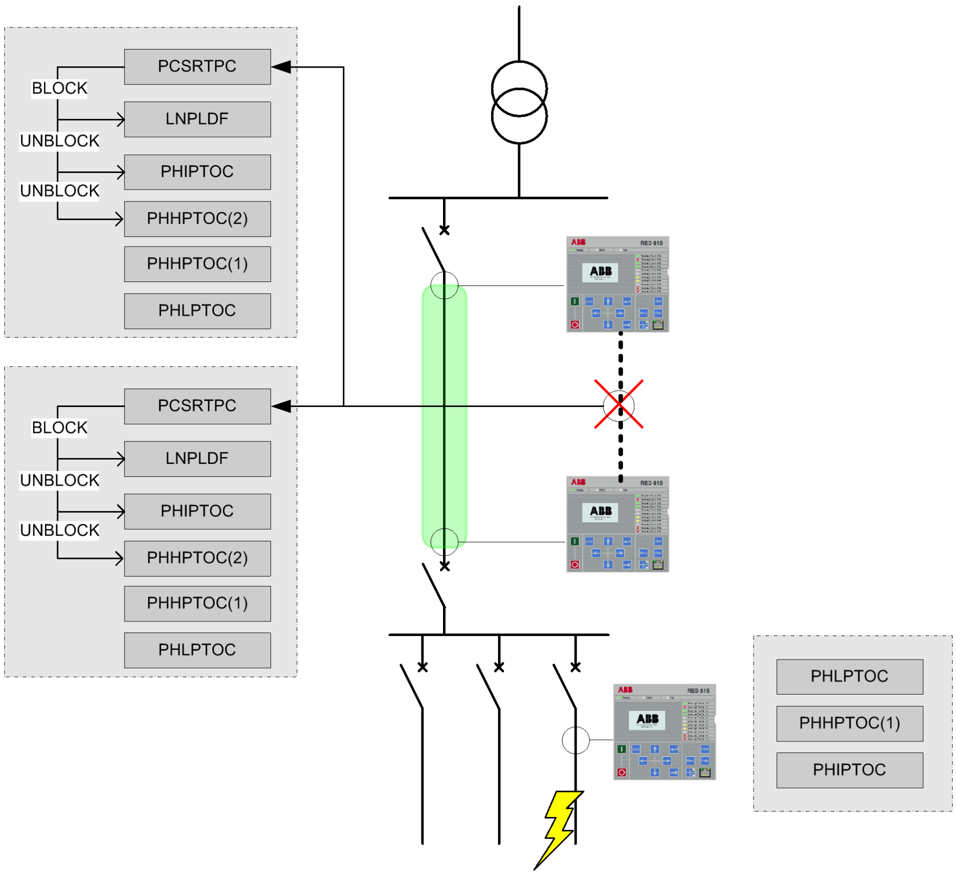
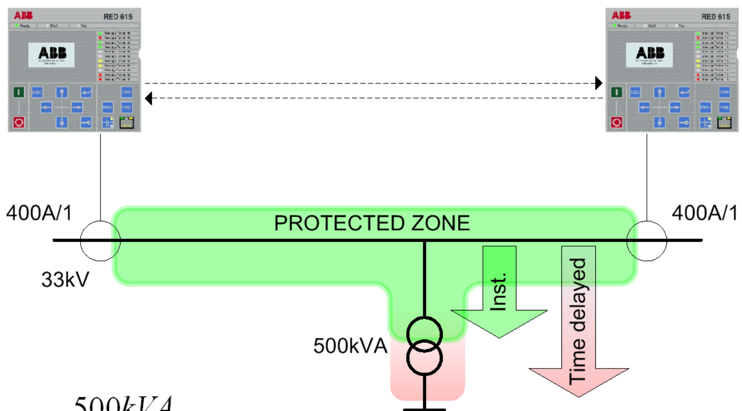


Figure 20: Protection communication supervision detects failures on communication

Small power transformers in a tap

With a relatively small power transformer in a line tap, the line differential protection can be applied without the need of current measurement from the tap. In such cases,

the line differential function is time delayed for low differential currents below the high set limit and LNPLDF coordinates with the downstream IEDs in the relevant tap. For differential currents above the set limit, the operation is instantaneous. As a consequence, when the load current of the tap is negligible, the low resistive line faults are cleared instantaneously at the same time as maximum sensitivity for the high resistive faults are maintained but with a time delayed operation.

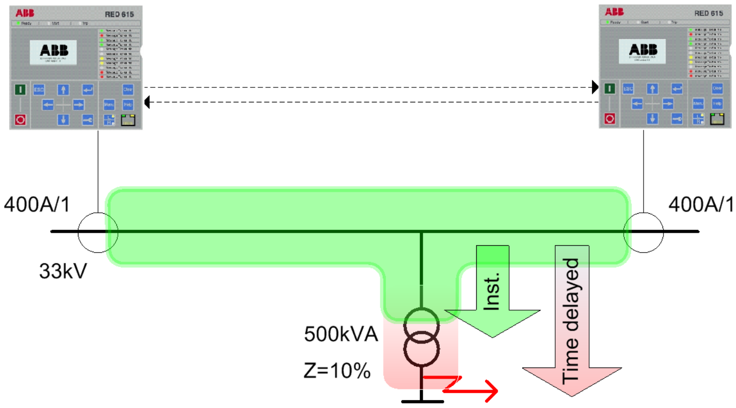


$$I_L = \frac{500kVA}{\sqrt{3} \cdot 33kV} \cong 8.75A$$

$$\mathrm{I}_{\Delta} > \left[\frac{8.75A}{400\ A}\right] * 1\mathrm{A} = 0.02A = 2\%$$

Figure 21: Influence of the tapped transformer load current to the stabilized low stage setting

The stabilized stage provides both DT and IDMT characteristics that are used to provide time selective protection against faults external to the instantaneous stage coverage. The impedance of the line is typically an order of magnitude lower than the transformer impedance providing significantly higher fault currents when the fault is located on the line.



$$I_F = \frac{1.1 \cdot 500kVA}{\sqrt{3} \cdot 33kV \cdot 0.10} \cong 96.23A$$

$$\mathrm{I}_\Delta < \left[\frac{96.23A}{400\ A}\right] * 1\mathrm{A} = 0.24A = 24\%$$

Figure 22: Influence of the short circuit current at LV side of the tapped transformer to the differential current

Detection of the inrush current during transformer start-up

When the line is energized, the transformer magnetization inrush current is seen as differential current by the line differential protection and may cause malfunction of the protection if not taken into account. The inrush situation may only be detected on one end but the differential current is always seen on both ends. The inrush current includes high order harmonic components which can be detected and used as the blocking criteria for the stabilized stage. The inrush detection information is changed between two ends so that fast and safe blocking of the stabilized stage can be issued on both ends.

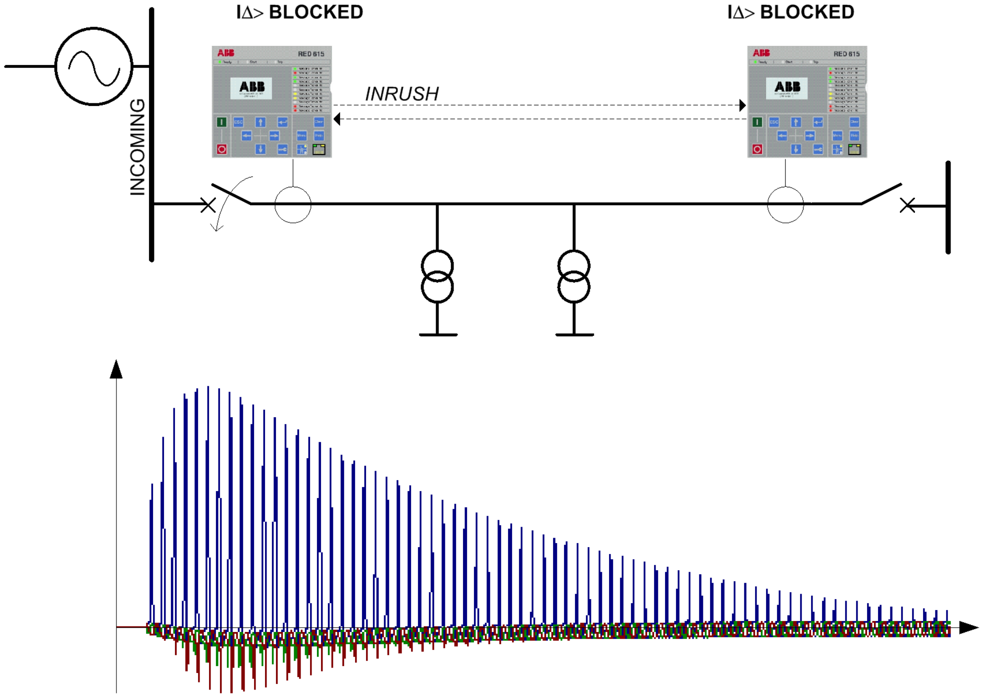


Figure 23: Blocking of line differential functions during detected transformer startup current

If the protection stage is allowed to start during the inrush situation, the time delay can be selected in such a way that the stabilized stage does not operate in the inrush situation.

5.1.4 Commissioning

The commissioning of the line differential protection scheme would be difficult without any support features in the functionality because of the relatively long distance between the IEDs. This has been taken into consideration in the design of the line differential protection. The communication channel can be used for echoing the locally fed current phasors from the remote end. By using this mode, it is possible to verify that differential calculation is done correctly in each phase. Also, the protection communication operation is taken into account with the differential current calculation when this test mode is used.

5.1.4.1 Required material for testing the IED

- Calculated settings
- Terminal diagram
- Circuit diagrams
- Technical and application manuals of the IED
- Single of three-phase secondary current source
- Single phase primary current source

- Timer with start and stop interfaces
- Auxiliary voltage source for the IEDs
- PC with related software, a web browser for web HMI

The setting and configuration of the IED must be completed before testing.

The terminal diagram, available in the technical manual, is a general diagram of the IED. Note, that the same diagram is not always applicable to each specific delivery, especially for the configuration of all the binary inputs and outputs. Therefore, before testing, check that the available terminal diagram corresponds to the IED.

Also, the circuit diagrams of the application are recommended to be available. Especially these are required for checking the terminal block numbers of the current, trip, alarm and possibly other auxiliary circuits.

The technical and application manuals contain application and functionality summaries, function blocks, logic diagrams, input and output signals, setting parameters and technical data sorted per function.

The minimum requirement for a secondary current injection test device is the ability to work as a one phase current source.

Prepare the IED for the test before testing a particular function. Consider the logic diagram of the tested protection function when performing the test. All included functions in the IED are tested according to the corresponding test instructions in this chapter. The functions can be tested in any order according to user preferences. Therefore, the test instructions are presented in alphabetical order. Only the functions that are in use (*Operation* is set to "On") should be tested.

The response from the test can be viewed in different ways:

- Binary output signals
- Monitored data values in the local HMI (logical signals)
- A PC with a web browser for web HMI use (logical signals and phasors).

All used setting groups should be tested.

5.1.4.2 Checking the external optical and electrical connections

The user must check the installation to verify that the IED is connected to the other required parts of the protection system. The IED and all the connected circuits are to be de-energized during the check-up.

Checking CT circuits

The CTs must be connected in accordance with the terminal diagram provided with the IED, both with regards to phases and polarity. The following tests are recommended for every primary CT or CT core connected to the IED:

- Primary injection test to verify the current ratio of the CT, the correct wiring up to the protection IED and correct phase sequence connection (that is L1, L2, L3.)
- Polarity check to prove that the predicted direction of secondary current flow is correct for a given direction of primary current flow. This is an essential test for the proper operation of the directional function, protection or measurement in the IED.
- CT secondary loop resistance measurement to confirm that the current transformer secondary loop dc resistance is within specification and that there are no high resistance joints in the CT winding or wiring.
- CT excitation test to ensure that the correct core in the CT is connected to the IED. Normally only a few points along the excitation curve are checked to ensure that there are no wiring errors in the system, for example due to a mistake in connecting the CT's measurement core to the IED.
- CT excitation test to ensure that the CT is of the correct accuracy rating and that there are no short circuited turns in the CT windings. Manufacturer's design curves should be available for the CT to compare the actual results.
- Check the earthing of the individual CT secondary circuits to verify that each three-phase set of main CTs is properly connected to the station earth and only at one electrical point.
- Insulation resistance check.
- Phase identification of CT shall be made.

Both primary and secondary sides must be disconnected from the line and IED when plotting the excitation characteristics.

If the CT secondary circuit is opened or its earth connection is missing or removed without the CT primary being de-energized first, dangerous voltages may be produced. This can be lethal and damage, for example, insulation. The re-energizing of the CT primary should be inhibited as long as the CT secondary is open or unearthed.

Checking the power supply

Check that the auxiliary supply voltage remains within the permissible input voltage range under all operating conditions. Check that the polarity is correct.

Checking binary I/O circuits

Binary input circuits

Always check the entire circuit from the equipment to the IED interface to make sure that all signals are connected correctly. If there is no need to test a particular input, the corresponding wiring can be disconnected from the terminal of the IED during testing. Check all the connected signals so that both input voltage level and polarity are in accordance with the IED specifications. However, attention must be paid to the electrical safety instructions.

Binary output circuits

Always check the entire circuit from the IED to the equipment interface to make sure that all signals are connected correctly. If a particular output needs to be tested, the corresponding wiring can be disconnected from the terminal of the IED during testing. Check all the connected signals so that both load and polarity are in accordance with the IED specifications. However, attention must be paid to the electrical safety instructions.

Checking optical connections

Check that the Tx and Rx optical connections are correct.

5.1.4.3 Applying required settings for the IED

Download all calculated settings and measurement transformer parameters in the IED.

5.1.4.4 Connecting test equipment to the IED

Before testing, connect the test equipment according to the IED specific connection diagram.

Pay attention to the correct connection of the input and output current terminals. Check that the input and output logical signals in the logic diagram for the function under test are connected to the corresponding binary inputs and outputs of the IED. Also, pay attention to selecting the correct auxiliary voltage source according to the power supply module of the IED. Also, pay attention to selecting the correct auxiliary voltage source according to the power supply module of the IED.

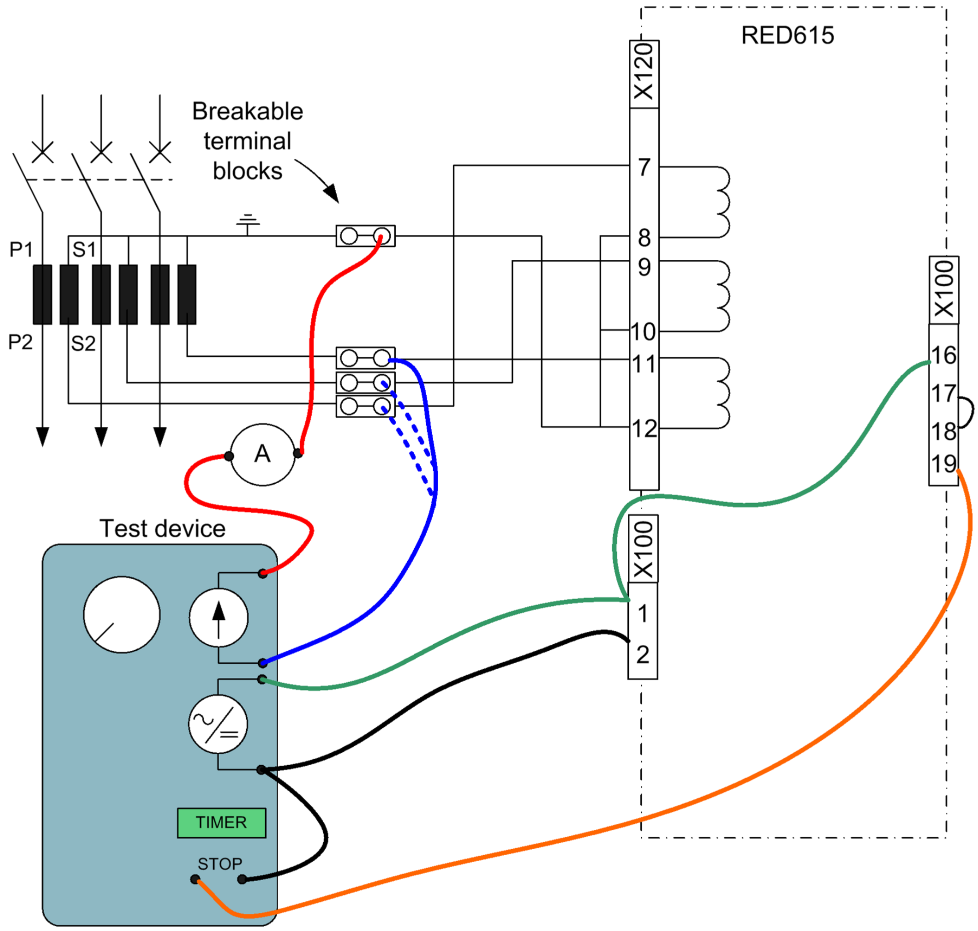


Figure 24: Example of connections to test the line differential IED

5.1.4.5 Secondary current injection

There are two alternative modes to check the operation of a line differential IED. These are not exclusive methods for each other and can be used for various test on the IED.

Normal mode

In normal mode, that is, the mode when the function is on normal operation, the local end IED sends phasors to the remote end IED and receives phasors measured by the remote end IED. This mode can be used in testing the operating level and time of the low and high stages of the local end IED. This is due to a test situation when the remote end does not measure any current and therefore, all the current fed to the local end current circuit is seen as differential current at both ends.

Testing of the line differential protection is done with both IEDs separated geographically from each other. It is important to note that local actions in one IED cause operation also in the remotely located IED. When testing the line differential function, actions have to be done in both IEDs.

Before the test, the trip signal to the circuit breaker shall be blocked, for example by breaking the trip circuit by opening the terminal block or by using some other suitable method.

When injecting current to one phase in the local end IED, the current is seen as a differential current at both ends. If a current $I_{injected}$ is injected, L1 in phase L1, the differential and stabilizing currents for phase L1 are:

$$IDIFF\_A = 2 \times IBIAS\_A = I_{injected}$$

(Equation 1)

The operation is equal for phases L2 and L3.

Verifying the settings

Procedure

1. Block the unwanted trip signals from the IED units involved.
2. Inject a current in phase L1 and increase the current until the function operates for phase L1.
   The injected operate current shall correspond to the set *Low operate value*. The monitored values for IDIFF_A and IBIAS_A should be equal to the injected current.
3. Repeat point 2 by current injection in phases L2 and L3.
4. Measure the operating time by injecting the single-phase current in phase 1.
   The injected current should be four times the operating current. The time measurement is stopped by the trip output from the IED unit.
5. Disconnect the test equipment and reconnect the current transformers and all other circuits including the trip circuit.

Phasor echoing method

The line differential function in one IED can be set to special test mode, that is, the *Operation* setting is set to “Test/blocked”. When this mode is in use, the remote end IED echoes locally injected current phasors back with the shifted phase and settable amplitude. The local end line differential function is also automatically blocked during this and the remote end line differential function discards the phasors it receives from the IED that is in the test mode

When the test mode is active, the *CT connection type* and *CT ratio correction* setting parameter values are still used by the line differential protection function as in the normal operation mode. These can be used for shifting the phase (0 or 180 degrees) and setting the amplitude of the echoed back phasors. For example, if three phase currents are injected to the local end IED which is also set to the test mode, the selected *CT connection type* is "Type 2" and the *CT ratio correction* setting parameter value is 0.500.

Parameter Setting

Group/Parameter Name	IED Value	New Value	Unit	Min.	Max.	Step
Operation	test/blocked	test/blocked				
High operate value	2000	2000	%	200	4000	
High Op value Mult	1.0	1.0		0.5	1.0	
Low operate value	10	10	%	10	200	
End section 1	100	100	%	0	200	
Slope section 2	50	50	%	10	50	
End section 2	500	500	%	200	2000	
Slope section 3	150	150	%	100	200	
Operate delay time	100	100	ms	40	200000	
Operating curve type	IEC Def. Time	IEC Def. Time				
Time multiplier	1.00	1.00		0.05	15.00	
Start value 2.H	20	20	%	10	50	
Restraint mode	None	None				
Reset delay time	0	0	ms	0	60000	
Minimum operate time	40	40	ms	40	60000	
CT ratio correction	0.500	0.500		0.200	5.000	
CT connection type	Type 2	Type 2				

Figure 25: An example of a test mode situation where three phase currents are injected to the local end IED

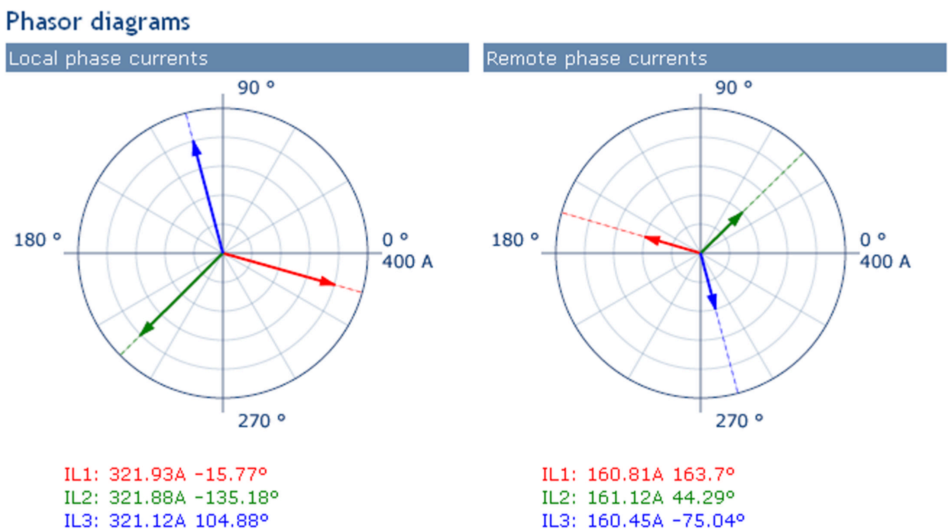


Figure 26: Local and remote end currents presented in a web HMI of the IED

5.2 Three-phase current protection

5.2.1 Three-phase non-directional overcurrent protection PHxPTOC

5.2.1.1 Identification

Table 29: Function identification

Different stages:	Low stage	High stage	Instantaneous stage
IEC 61850 identification:	PHLPTOC	PHHPTOC	PHIPTOC
IEC 60617 identification:	3I>	3I>>	3I>>>
ANSI/IEEE C37.2 device number:	51P-1	51P-2	50P/51P

5.2.1.2 Functionality

The three-phase overcurrent protection PHxPTOC is used as one-phase, two-phase or three-phase non-directional overcurrent and short-circuit protection for feeders.

The function starts when the current exceeds the set limit. The operate time characteristics for low stage PHLPTOC and high stage PHHPTOC can be selected to be either definite time (DT) or inverse definite minimum time (IDMT).The instantaneous stage PHIPTOC always operates with the DT characteristic.

In the DT mode, the function operates after a predefined operate time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

5.2.1.3 Application

PHxPTOC is used in several applications in the power system. The applications include but are not limited to:

- Selective overcurrent and short-circuit protection of feeders in distribution and subtransmission systems
- Back-up overcurrent and short-circuit protection of power transformers and generators
- Overcurrent and short-circuit protection of various devices connected to the power system, for example, shunt capacitor banks, shunt reactors and motors
- General back-up protection.

PHxPTOC is used for single-phase, two-phase and three-phase non-directional overcurrent and short-circuit protection. Typically, overcurrent protection is used for clearing two and three-phase short circuits. Therefore, the user can choose how many phases, at minimum, must have currents above the start level for the function to operate. When the number of start-phase settings is set to "1 out of 3", the operation of PHxPTOC is enabled with the presence of high current in one-phase.

When the setting is "2 out of 3" or "3 out of 3", single-phase faults are not detected. The setting "3 out of 3" requires the fault to be present in all three phases.

Many applications require several steps using different current start levels and time delays. PHxPTOC consists of three protection stages:

- Low PHLPTOC
- High PHHPTOC
- Instantaneous PHIPTOC.

PHLPTOC is used for overcurrent protection. The function contains several types of time-delay characteristics. PHHPTOC and PHIPTOC are used for fast clearance of very high overcurrent situations.

Overcurrent protection with line differential protection

The line differential IED has also four separate overcurrent functions which can be used as the backup protection of line differential function for lines and cables. There are three stages available with definite or inverse time characteristics and an instantaneous stage.

The differential protection is available only if the communication between the units is working properly and no CT failure situation is detected. If a communication failure exists, the protect area or unit is left out from the primary protection scheme. Therefore it is practical to use overcurrent protection as a local backup functionality.

In the standard configuration of the IED, the backup overcurrent protection is implemented with four overcurrent stages so that under normal conditions, that is, when the line differential communication is healthy, only two lowest stages are available for the remote backup protection. In case a line differential communication failure exists, two more stages are released for rapid local backup overcurrent and short circuit protection. These stages are blocked in normal situation and automatically unblocked when the communication failure is detected. The setting of the overcurrent stages for local backup protection has to be considered carefully in order to achieve the best possible protection performance under abnormal conditions.

Two situations, case A and B, are shown in Figure 27. In case A, the communication media is valid and therefore the line differential protection is in operation. In this case, the two lowest stages of overcurrent protection are in operation simultaneously. In case B, a communication failure causes a situation where the line differential function is not able to work properly. Unblocking of the two highest overcurrent protection

stages releases these functions to protect the line against over currents and short-circuits.

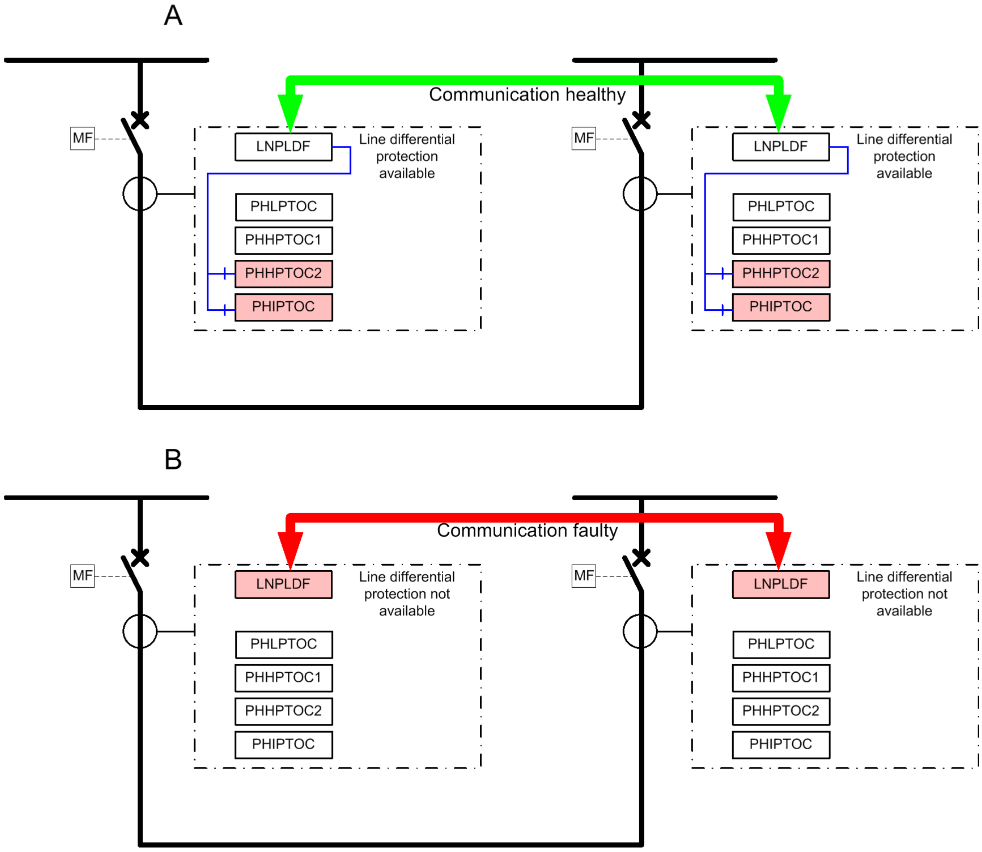


Figure 27: Backup overcurrent protection for line differential applications

Transformer and busbar overcurrent protection with reverse blocking principle

By implementing a full set of overcurrent protection stages and blocking channels between the protection stages of the incoming feeders, bus-tie and outgoing feeders, it is possible to speed up the operation of overcurrent protection in the busbar and transformer LV-side faults without impairing the selectivity. Also, the security degree of busbar protection is increased, because there is now a dedicated, selective and fast busbar protection functionality, which is based on the blockable overcurrent protection principle. The additional time selective stages on the transformer HV- and LV-sides provide increased security degree of back-up protection for the transformer, busbar and also for the outgoing feeders.

Depending on the overcurrent stage in question, the selectivity of the scheme in Figure 28 is based on the operating current, operating time or blockings between successive overcurrent stages. With blocking channels the operating time of the protection can be drastically shortened, if compared to the simple time selective protection. In addition to the busbar protection, this blocking principle is applicable for the protection of transformer LV terminals and short lines. The functionality and

performance of the proposed overcurrent protections can be summarized as seen in the table.

Table 30: Proposed functionality of numerical transformer and busbar over current protection. DT = definite time, IDMT = inverse definite minimum time

O/C-stage	Operating char.	Selectivity mode	Operation speed	Sensitivity
HV/3I>	DT/IDMT	time selective	-	+ +
HV/3I>>	DT	blockable/time selective	+/-	+
HV/3I>>>	DT	current selective	+ +	-
LV/3I>	DT/IDMT	time selective	-	+ +
LV/3I>>	DT	time selective	-	+
LV/3I>>>	DT	blockable	+	+

In case the bus-tie breaker is open, the operating time of the blockable overcurrent protection is approximately 100 ms (relaying time). When the bus-tie breaker is closed, that is, the fault current flows to the faulted section of the busbar from two directions, the operation time becomes as follows: first the bus-tie relay unit trips the tie breaker in the above 100 ms, which reduces the fault current in to a half. After this the incoming feeder relay unit of the faulted bus section trips the breaker in approximately 250 ms (relaying time), which becomes the total fault clearing time in this case.

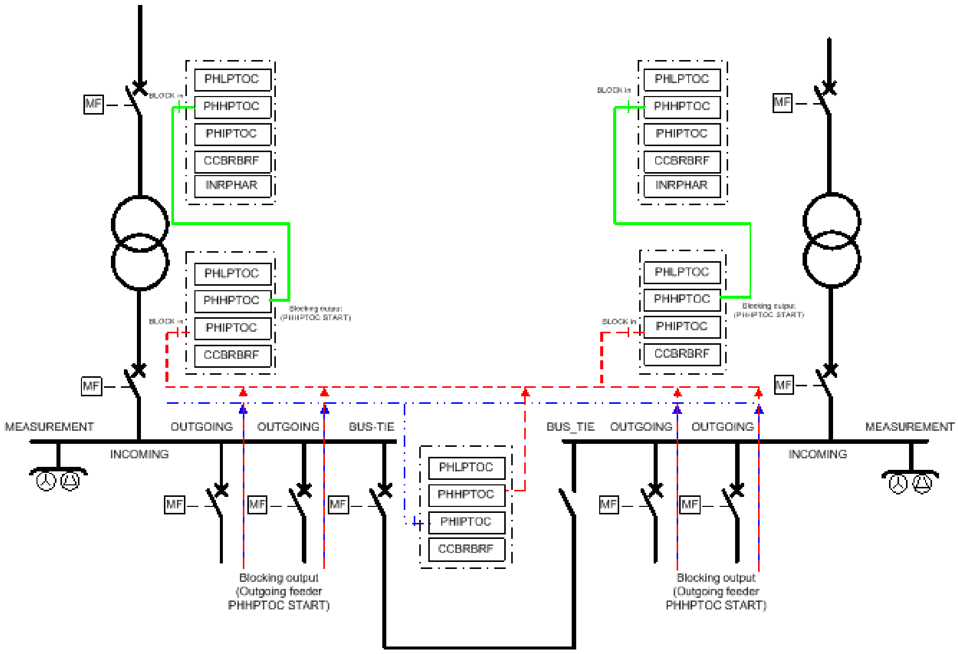


Figure 28: Numerical overcurrent protection functionality for a typical sub-transmission/distribution substation (feeder protection not shown). Blocking output = digital output signal from the start of a protection stage, Blocking in = digital input signal to block the operation of a protection stage

The operating times of the time selective stages are very short, because the grading margins between successive protection stages can be kept short. This is mainly due to the advanced measuring principle allowing a certain degree of CT saturation, good operating accuracy and short retardation times of the numerical units. So, for example, a grading margin of 150 ms in the DT mode of operation can be used, provided that the circuit breaker interrupting time is shorter than 60 ms.

The sensitivity and speed of the current-selective stages become as good as possible due to the fact that the transient overreach is practically zero. Also, the effects of switching inrush currents on the setting values can be reduced by using the IED logic, which recognizes the transformer energizing inrush current and blocks the operation or multiplies the current start value setting of the selected overcurrent stage with a predefined multiplier setting.

Finally, a dependable trip of the overcurrent protection is secured by both a proper selection of the settings and an adequate ability of the measuring transformers to reproduce the fault current. This is important in order to maintain selectivity and also for the protection to operate without additional time delays. For additional information about available measuring modes and current transformer requirements, refer to section where general function block features are described in the IED technical manual.

Radial outgoing feeder over current protection

The basic requirements for feeder overcurrent protection are adequate sensitivity and operation speed taking into account the minimum and maximum fault current levels along the protected line, selectivity requirements, inrush currents and the thermal and mechanical withstand of the lines to be protected.

In many cases the above requirements can be best fulfilled by using a multiple-stage over current units. Figure 29 shows an example of this. A brief coordination study has been carried out between the incoming and outgoing feeders.

The protection scheme is implemented with three-stage numerical over current protection, where the low-set stage PHLPTOC operates in IDMT-mode and the two higher stages PHHPTOC and PHIPTOC in DT-mode. Also the thermal withstand of the line types along the feeder and maximum expected inrush currents of the feeders are shown. Faults occurring near the station, where the fault current levels are the highest, are cleared rapidly by the instantaneous stage in order to minimize the effects of severe short circuit faults. The influence of the inrush current is taken into consideration by connecting the inrush current detector to the start value multiplying input of the instantaneous stage. By this way the start value is multiplied with a predefined setting during the inrush situation and nuisance tripping can be avoided.

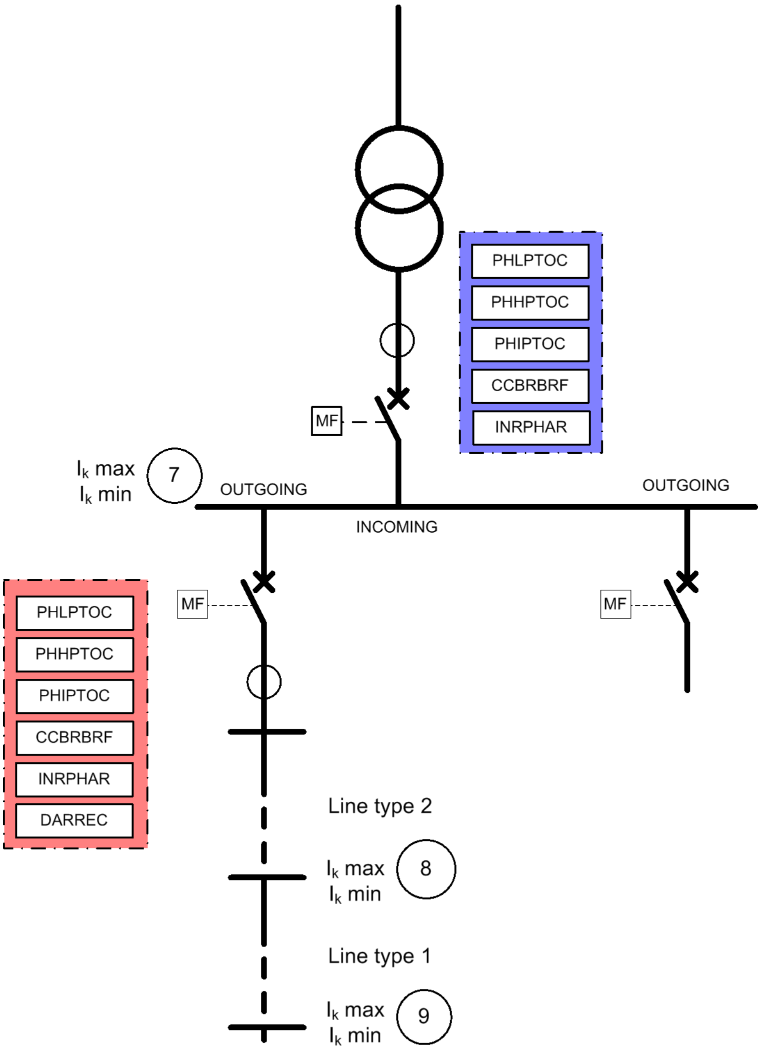


Figure 29: Functionality of numerical multiple-stage overcurrent protection

The coordination plan is an effective tool to study the operation of time selective operation characteristics. All the points mentioned earlier, required to define the overcurrent protection parameters, can be expressed simultaneusly in a coordination plan. In Figure 30 the coordination plan shows an example of operation characteristics in the LV-side incoming feeder and radial outgoing feeder.

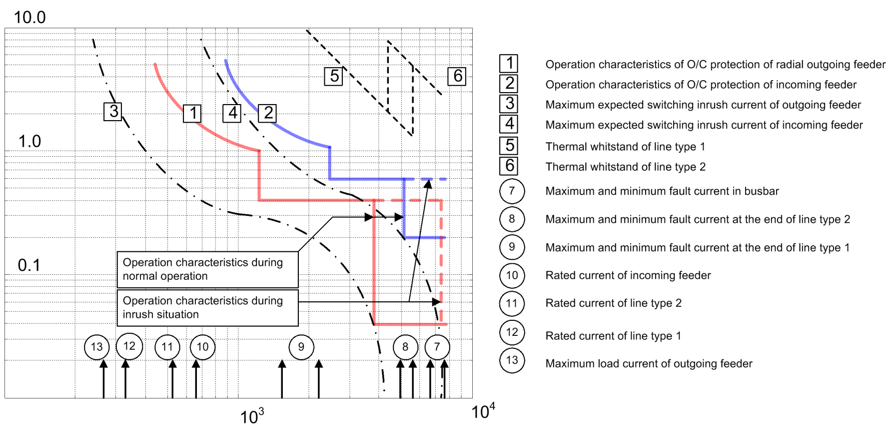


Figure 30: Example coordination of numerical multiple-stage over current protection

5.3 Unbalance protection

5.3.1 Negative phase-sequence current protection NSPTOC

5.3.1.1 Identification

Table 31: Function identification

IEC 61850 identification:	NSPTOC
IEC 60617 identification:	I2>
ANSI/IEEE C37.2 device number:	46

5.3.1.2 Functionality

The negative phase-sequence current protection NSPTOC is used for increasing sensitivity to detect single phasing situations, unbalanced loads due to, for example, broken conductors or to unsymmetrical feeder voltages.

The function is based on the measurement of the negative phase-sequence current. In a fault situation, the function starts when the negative phase sequence current exceeds the set limit. The operate time characteristics can be selected to be either definite time (DT) or inverse definite minimum time (IDMT). In the DT mode, the function operates after a predefined operate time and resets when the fault current disappears. The IDMT mode provides current dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers, or the function itself, if desired.

5.3.1.3 Application

Since the negative sequence current quantities are not present during normal, balanced load conditions, the negative sequence overcurrent protection elements can be set for faster and more sensitive operation than the normal phase-overcurrent protection for fault conditions occurring between two phases. The negative sequence overcurrent protection also provides a back-up protection functionality for the feeder earth-fault protection in solid and low resistance earthed networks.

The negative sequence overcurrent protection provides the back-up earth-fault protection on the high voltage side of a delta-wye connected power transformer for earth faults taking place on the wye-connected low voltage side. If an earth fault occurs on the wye-connected side of the power transformer, negative sequence current quantities appear on the delta-connected side of the power transformer.

Multiple time curves and time multiplier settings are also available for coordinating with other devices in the system.

Section 6 Protection related functions

6.1 Three-phase inrush detector INRPHAR

6.1.1 Identification

Table 32: Function identification

IEC 61850 identification:	INRPHAR
IEC 60617 identification:	3I2f>
ANSI/IEEE C37.2 device number:	68

6.1.2 Functionality

The transformer inrush detection INRPHAR is used to coordinate transformer inrush situations in distribution networks.

Transformer inrush detection is based on the following principle: the output signal `BLK2H` is activated once the numerically derived ratio of second harmonic current I_2H and the fundamental frequency current I_1H exceeds the set value.

The operate time characteristic for the function is of definite time (DT) type.

The function contains a blocking functionality. Blocking deactivates all outputs and resets timers.

6.1.3 Application

Transformer protections require high stability to avoid tripping during magnetizing inrush conditions. A typical example of an inrush detector application is doubling the *Start value* of an overcurrent protection during inrush detection.

The inrush detection function can be used to selectively block overcurrent and earth-fault function stages when the ratio of second harmonic component over the fundamental component exceeds the set value.

Other applications of this function include the detection of inrush in lines connected to a transformer.

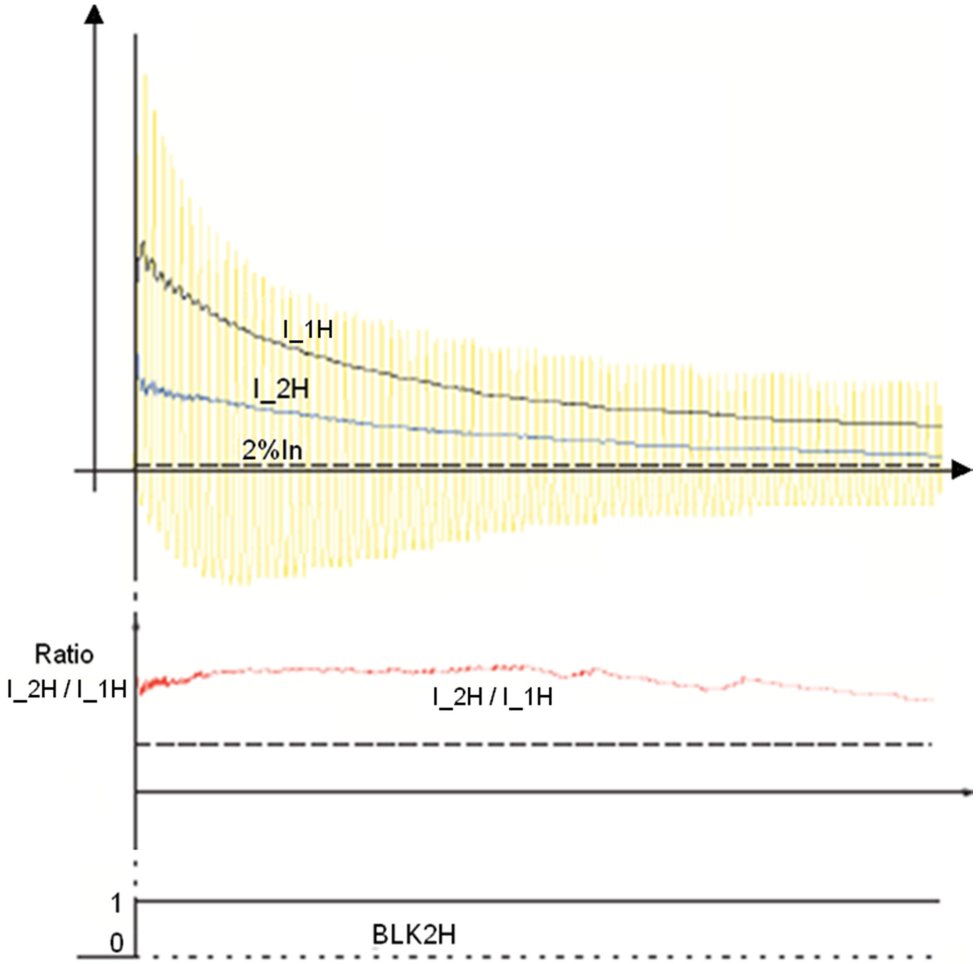


Figure 31: Inrush current in transformer

6.2 Circuit breaker failure protection CCBRBRF

6.2.1 Identification

Table 33: Function identification

IEC 61850 identification:	CCBRBRF
IEC 60617 identification:	$3I>I_0>BF$
ANSI/IEEE C37.2 device number:	51BF/51NBF

6.2.2 Functionality

The breaker failure function CCBRBRF is activated by trip commands from the protection functions. The commands are either internal commands to the terminal or

external commands through binary inputs. The start command is always a default for three-phase operation. CCBRBRF includes a three-phase conditional or unconditional re-trip function, and also a three-phase conditional back-up trip function.

CCBRBRF uses the same levels of current detection for both re-trip and back-up trip. The operating values of the current measuring elements can be set within a predefined setting range. The function has two independent timers for trip purposes: a re-trip timer for the repeated tripping of its own breaker and a back-up timer for the trip logic operation for upstream breakers. A minimum trip pulse length can be set independently for the trip output.

The function contains a blocking functionality. It is possible to block the function outputs, if desired.

6.2.3 Application

The n-1 criterion is often used in the design of a fault clearance system. This means that the fault is cleared even if some component in the fault clearance system is faulty. A circuit breaker is a necessary component in the fault clearance system. For practical and economical reasons, it is not feasible to duplicate the circuit breaker for the protected component, but breaker failure protection is used instead.

The breaker failure function issues a back-up trip command to adjacent circuit breakers in case the original circuit breaker fails to trip for the protected component. The detection of a failure to break the current through the breaker is made by measuring the current or by detecting the remaining trip signal (unconditional).

CCBRBRF can also retrip. This means that a second trip signal is sent to the protected circuit breaker. The retrip function is used to increase the operational reliability of the breaker. The function can also be used to avoid back-up tripping of several breakers in case mistakes occur during relay maintenance and tests.

CCBRBRF is initiated by operating different protection functions or digital logics inside the IED. It is also possible to initiate the function externally through a binary input.

CCBRBRF can be blocked by using an internally assigned signal or an external signal from a binary input. This signal blocks the function of the breaker failure protection even when the timers have started or the timers are reset.

The retrip timer is initiated after the start input is set to true. When the pre-defined time setting is exceeded, CCBRBRF issues the retrip and sends a trip command, for example, to the circuit breaker's second trip coil. Both a retrip with current check and an unconditional retrip are available. When a retrip with current check is chosen, the retrip is performed only if there is a current flow through the circuit breaker.

The back-up trip timer is also initiated at the same time as the retrip timer. If CCBRBRF detects a failure in tripping the fault within the set back-up delay time, which is longer than the retrip time, it sends a back-up trip signal to the chosen back-

up breakers. The circuit breakers are normally upstream breakers which feed fault current to a faulty feeder.

The back-up trip always includes a current check criterion. This means that the criterion for a breaker failure is that there is a current flow through the circuit breaker after the set back-up delay time.

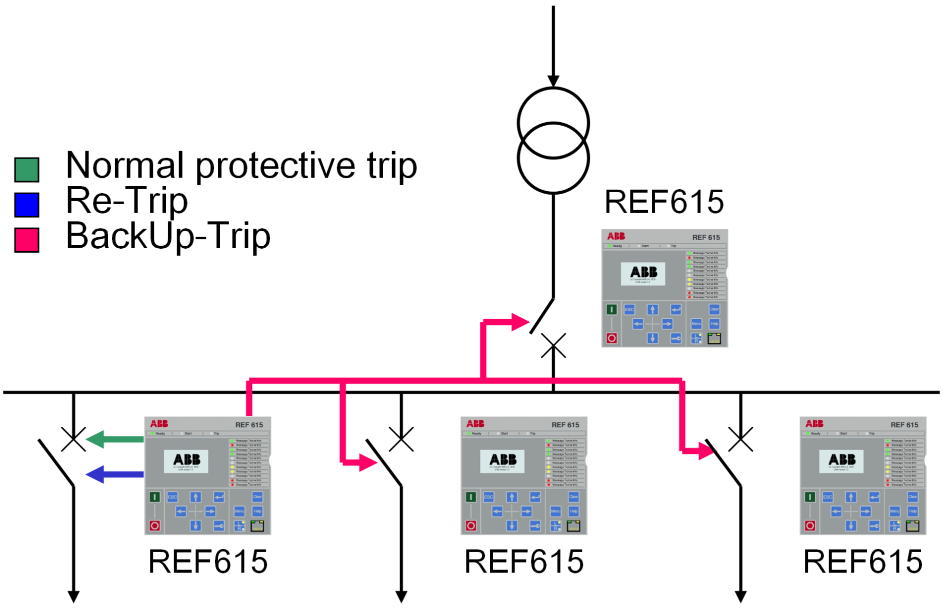


Figure 32: Typical breaker failure protection scheme in distribution substations

6.3 Protection trip conditioning TRPPTRC

6.3.1 Identification

Table 34: Function identification

IEC 61850 identification:	TRPPTRC
IEC 60617 identification:	I->O
ANSI/IEEE C37.2 device number:	94

6.3.2 Functionality

The protection trip conditioning function TRPPTRC is used as a trip command collector and handler after the protection functions. The features of this function influence the trip signal behavior of the circuit breaker. The user can set the minimum trip pulse length when the non-latched mode is selected. It is also possible to select the latched or lockout mode for the trip signal.

6.3.3 Application

All trip signals from different protection functions are routed through the trip logic. The most simplified alternative of a logic function is linking the trip signal and ensuring that the signal is long enough.

The tripping logic in the protection relay is intended to be used in the three-phase tripping for all fault types (3ph operating). To prevent the closing of a circuit breaker after a trip, the function can block the CBXCBR closing.

The TRPPTRC function is intended to be connected to one trip coil of the corresponding circuit breaker. If tripping is needed for another trip coil or another circuit breaker which needs, for example, different trip pulse time, another trip logic function can be used. The two instances of the PTRC function are identical, only the names of the functions, TRPPTRC1 and TRPPTRC2, are different. Therefore, even if all references are made only to TRPPTRC1, they also apply to TRPPTRC2.

The inputs from the protection functions are connected to the `OPERATE` input. Usually, a logic block OR is required to combine the different function outputs to this input. The `TRIP` output is connected to the digital outputs on the IO board. This signal can also be used for other purposes within the IED, for example when starting the breaker failure protection.

TRPPTRC is used for simple three-phase tripping applications.

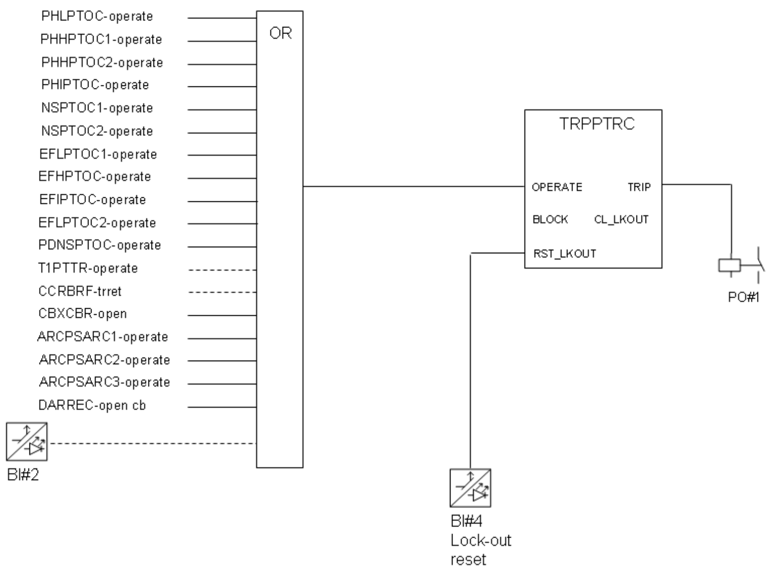


Figure 33: Typical TRPPTRC connection

Lockout

TRPPTRC is provided with possibilities to activate a lockout. When activated, the lockout can be manually reset after checking the primary fault by activating the RST_LKOUT input or from the LHMI clear menu parameter. When using the “Latched” mode, the resetting of the TRIP output can done similarly as when using the “Lockout” mode. It is also possible to reset the “Latched” mode remotely through a separate communication parameter.

The minimum pulse trip pulse function is not active when using the “Lockout” or “Latched” modes but only when the “Non-latched” mode is selected.

6.4 Binary signal transfer BSTGGIO

6.4.1 Identification

Table 35: Function identification

IEC 61850 identification:	BSTGGIO
IEC 60617 identification:	BST
ANSI/IEEE C37.2 device number:	BST

6.4.2 Functionality

The binary signal transfer function BSTGGIO is used for transferring binary signals between the local and remote end line differential protection IEDs. The function includes eight binary signals that are transferred in the protection communication telegram and can be freely configured and used for any purpose in the line differential application.

BSTGGIO transfers binary data continuously over the protection communication channel between the terminals. Each of the eight signals are bidirectional and the binary data sent locally is available remotely as a received signal.

BSTGGIO includes a minimum pulse time functionality for the received binary signals. Each received signal has its own minimum pulse time setting parameter.

BSTGGIO includes two alarm output signals. The SEND_SIG_A output signal is updated according to the status of the sent binary signals. The RECV_SIG_A output signal is updated according to the status of the received binary signals. Each signal can be separately included or excluded from the alarm logic with a setting parameter.

6.4.3 Application

Among with the analog data, the binary data can also be exchanged with the line differential protection IEDs. The usage of the binary data is application specific and can vary in each separate case. The demands for the speed of the binary signals vary depending on the usage of the data. When the binary data is used as blocking signals for the line differential protection, the transfer response is extremely high. Binary signal interchange can be used in applications such as:

- Remote position indications
- Inter-tripping of the circuit breakers on both line ends
- Blocking of the line differential protection during transformer inrush or current circuit supervision failure
- Protection schemes; blocking or permissive
- Remote alarming.

The figure shows the overall chain to transfer binary data in an example application. The position indication of the local circuit breaker is connected to the IED's input interface and is then available for the IED configuration. The circuit breaker position indication is connected to the first input of BSTGGIO which is used to send information to the remote end via communication. In the remote end, this information is handled as a remote circuit breaker open position and it is available from the first output of BSTGGIO. This way the information can be exchanged.

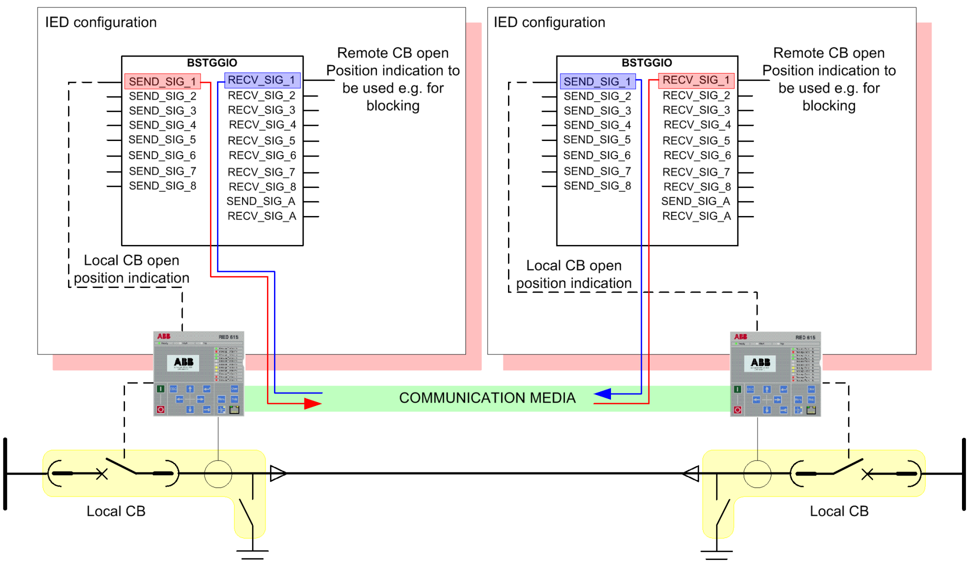


Figure 34: Example of usage of binary signal transfer for position indication change

Section 7 Supervision functions

7.1 Trip circuit supervision TCSSCBR

7.1.1 Identification

Table 36: Function identification

IEC 61850 identification:	TCSSCBR
IEC 60617 identification:	TCS
ANSI/IEEE C37.2 device number:	TCM

7.1.2 Functionality

The trip circuit supervision function (TCSSCBR) is designed for supervision purposes of control circuits. The invalidity of a control circuit is detected by using a dedicated output contact that contains the supervision functionality.The failure of a circuit is reported to the corresponding function block in the IED configuration.

The function starts and operates when TCS detects a trip circuit failure. The operate time characteristic for the function is of DT type. The function operates after a predefined operating time and resets when the fault disappears.

The function contains a blocking functionality. Blocking deactivates the `ALARM` output and resets the timer.

7.1.3 Application

TCSSCBR detects faults in the electrical control circuit of the circuit breaker. The function can supervise both open and closed coil circuits. This kind of supervision is necessary to find out the vitality of the control circuits continuously.

The following figure shows an application of the trip-circuit supervision function usage. The best solution is to connect an external R_{ext} shunt resistor in parallel with the circuit breaker internal contact. Although the circuit breaker internal contact is open, TCS can see the trip circuit through R_{ext}. The R_{ext} resistor should have such a resistance that the current through the resistance remains small, that is, it does not harm or overload the circuit breaker's trip coil.

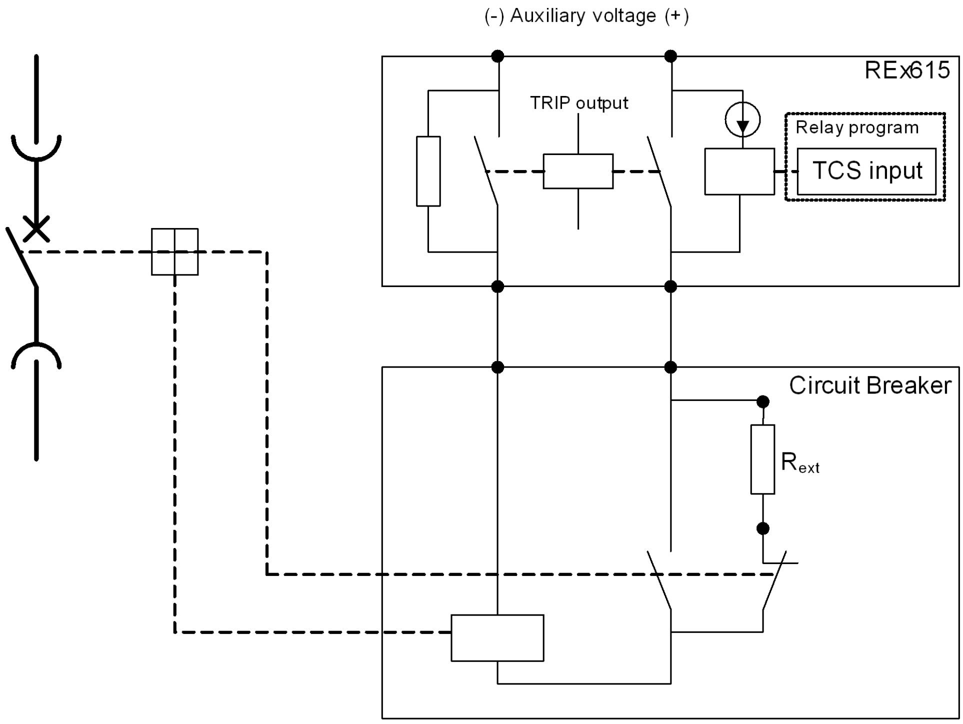


Figure 35: Circuit breaker trip-circuit supervision application with an external resistor

If the TCS is required only in a closed position, the external shunt resistance may be omitted. When the circuit breaker is in the open position, the TCS sees the situation as a faulty circuit. One way to avoid TCS operation in this situation would be to block the supervision function whenever the circuit breaker is open.

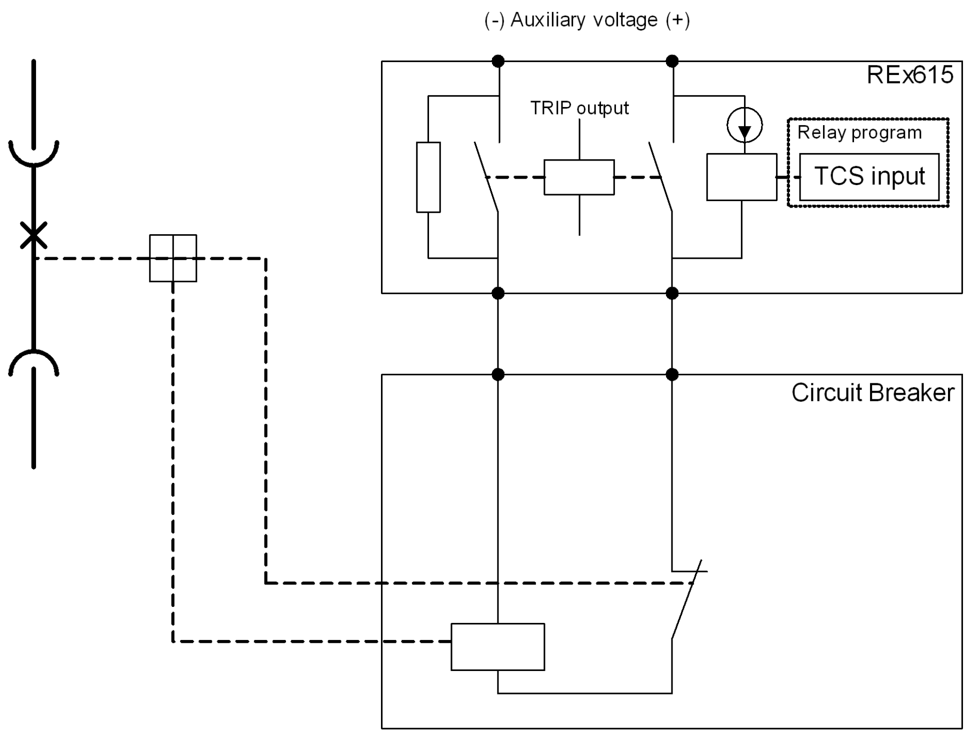


Figure 36: Circuit breaker trip-circuit supervision application without an external resistor

Trip-circuit supervision and other trip contacts

It is typical that the trip circuit contains more than one trip contact in parallel, for example in transformer feeders where the trip of a buchholz relay is connected in parallel with the feeder terminal and other relays involved. The constant test current flow is shown in the following figure. The supervising current cannot detect if one or all the other contacts connected in parallel are not connected properly.

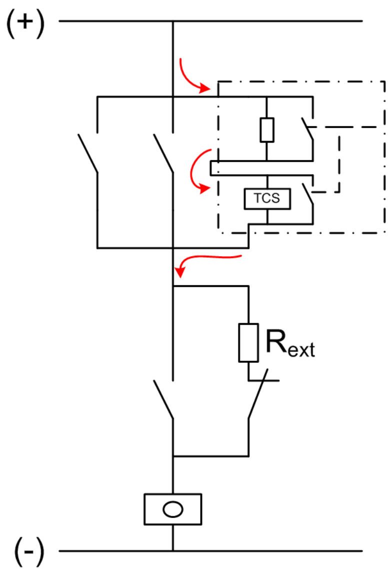


Figure 37: Current flow in parallel trip contacts and trip-circuit supervision

In case of parallel trip contacts, the recommended way to do the wiring is that the TCS test current flows through all wires and joints as shown in the following figure.

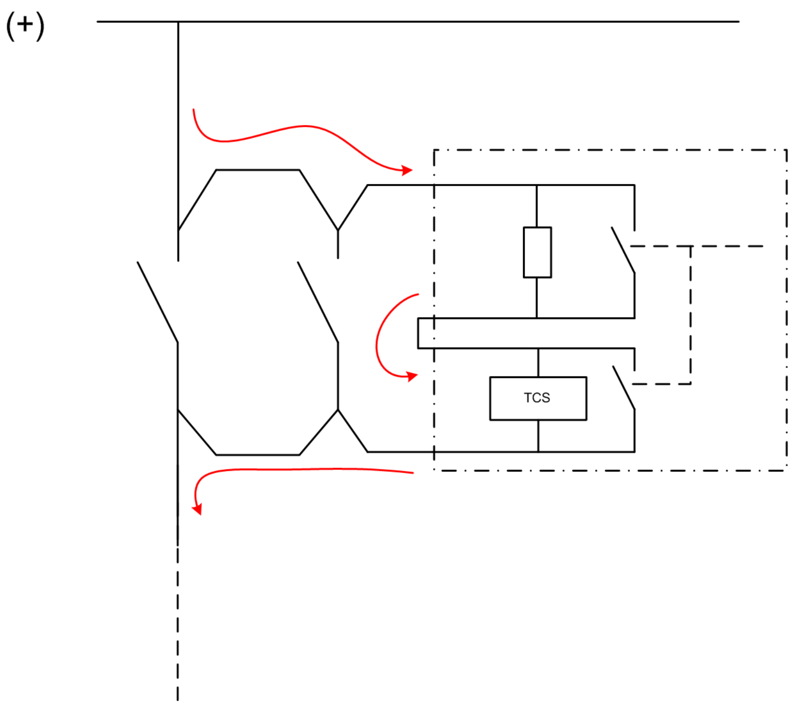


Figure 38: Improved connection for parallel trip contacts

Several trip-circuit supervision functions parallel in circuit

Not only the trip circuit often have parallel trip contacts, it is also possible that the circuit has multiple TCS circuits in parallel. Each TCS circuit causes its own

supervising current to flow through the monitored coil and the actual coil current is a sum of all TCS currents. This must be taken into consideration when determining the resistance of R_{ext}.

Setting the TCS function in a protection IED not-in-use does not typically effect the supervising current injection.

Trip-circuit supervision with auxiliary relays

Many retrofit projects are carried out partially, that is, the old electromechanical relays are replaced with new ones but the circuit breaker is not replaced. This creates a problem that the coil current of an old type circuit breaker may be too high for the protection IED trip contact to break.

The circuit breaker coil current is normally cut by an internal contact of the circuit breaker. In case of a circuit breaker failure, there is a risk that the protection IED trip contact is destroyed since the contact is obliged to disconnect high level of electromagnetic energy accumulated in the trip coil.

An auxiliary relay can be used between the protection IED trip contact and the circuit breaker coil. This way the breaking capacity question is solved, but the TCS circuit in the protection IED monitors the healthy auxiliary relay coil, not the circuit breaker coil. The separate trip circuit supervision relay is applicable for this to supervise the trip coil of the circuit breaker.

Dimensioning of the external resistor

Under normal operating conditions, the applied external voltage is divided between the relay's internal circuit and the external trip circuit so that at the minimum 20 V (15...20 V) remains over the relay's internal circuit. Should the external circuit's resistance be too high or the internal circuit's too low, for example, due to welded relay contacts, the fault is detected.

Mathematically, the operation condition can be expressed as:

$$U_c - (R_{ext} + R_{int} + R_s) x I_c \geq 20V\ AC / DC \quad \text{(Equation 2)}$$

U_c	Operating voltage over the supervised trip circuit
I_c	Measuring current through the trip circuit, appr. 1.5 mA (0.99...1.72 mA)
R_{ext}	external shunt resistance
R_{int}	internal shunt resistance, 1kW
R_s	trip coil resistance

If the external shunt resistance is used, it has to be calculated not to interfere with the functionality of the supervision or the trip coil. Too high a resistance will cause too high a voltage drop, jeopardizing the requirement of at least 20 V over the internal circuit, while a resistance too low may enable false operations of the trip coil.

Table 37: Values recommended for the external resistor R_{ext}

Operating voltage U_c	Shunt resistor R_{ext}
48 V DC	1.2 kΩ, 5 W
60 V DC	5.6 kΩ, 5 W
110 V DC	22 kΩ, 5 W
220 V DC	33 kΩ, 5 W

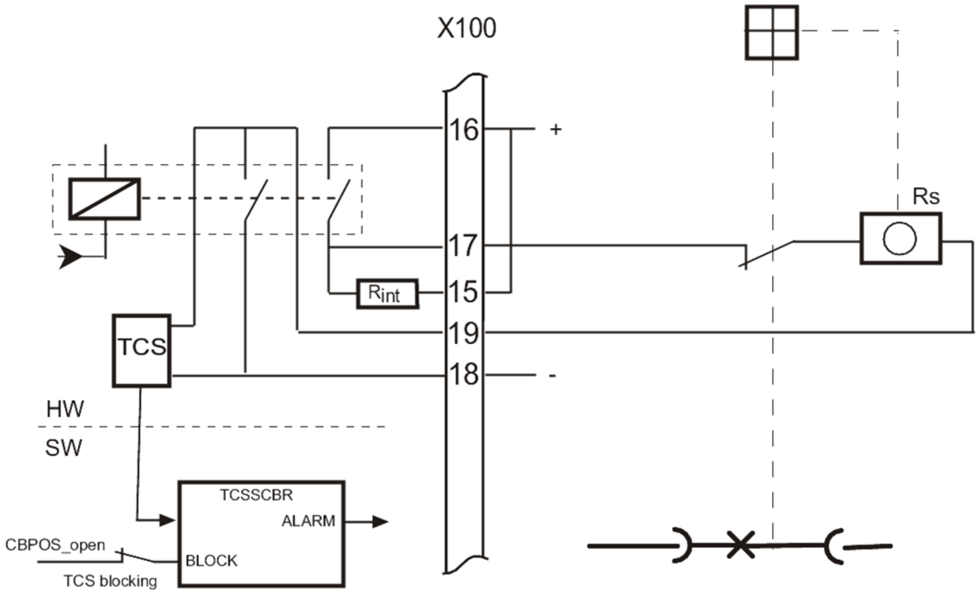


Figure 39: Operating principle of the trip-circuit supervision without an external resistor. The TCS blocking switch is set to block the TCSSCBR when the circuit breaker is open.

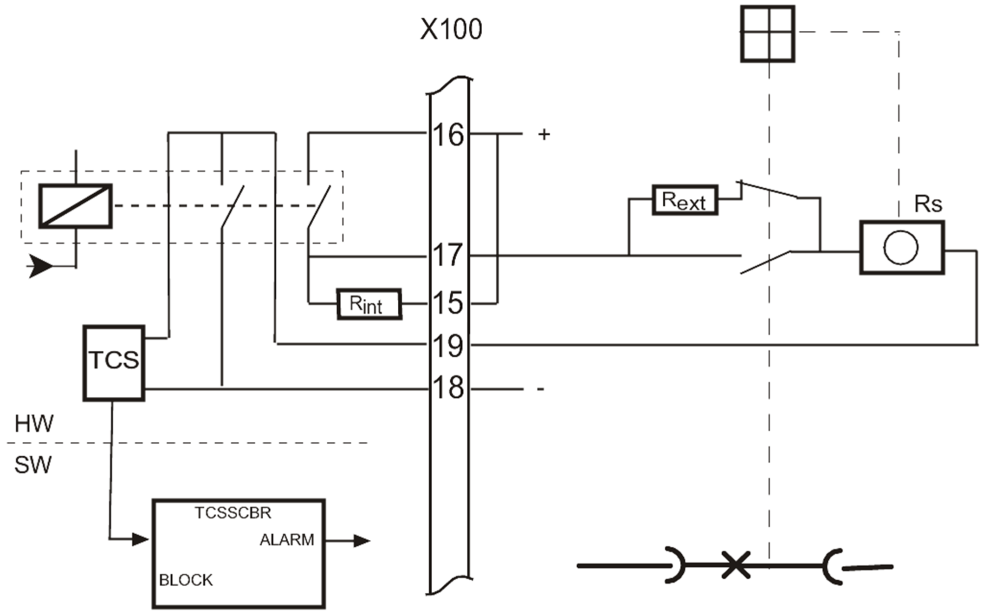


Figure 40: Operating principle of the trip-circuit supervision with an external resistor. The TCSSCBR blocking switch is open enabling the trip-circuit supervision to be independent of the circuit breaker position

Using power output contacts without trip-circuit supervision

If TCS is not used but the contact information of corresponding power outputs are required, the internal resistor can be by-passed. When bypassing the internal resistor, the wiring between the terminals of the corresponding output X100:16-15(PO3) or X100:21-20(PO4) can be disconnected. The internal resistor is required if the complete TCS circuit is used.

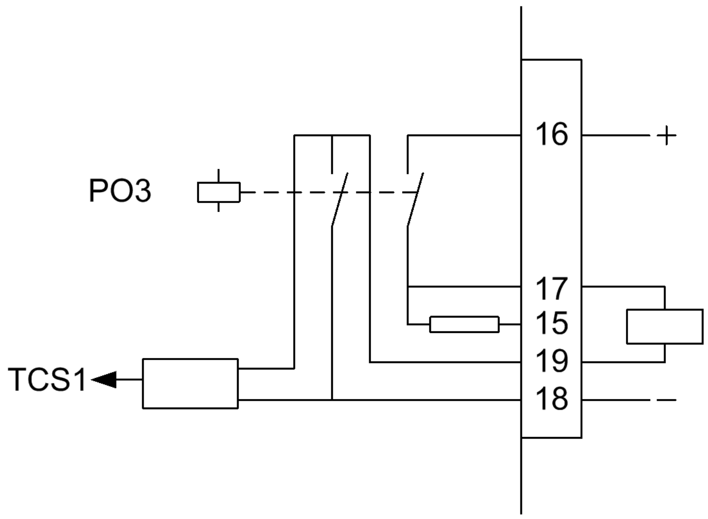


Figure 41: Connection of a power output in a case when TCS is not used and the internal resistor is disconnected

Incorrect connections and usage of trip-circuit supervision

Although the TCS circuit consists of two separate contacts, it must be noted that those are designed to be used as series connected to guarantee the breaking capacity given in the technical manual of the IED. In addition to the weak breaking capacity, the internal resistor is not dimensioned to withstand current without a TCS circuit. As a result, this kind of incorrect connection causes immediate burning of the internal resistor when the circuit breaker is in the close position and the voltage is applied to the trip circuit. The following picture shows incorrect usage of a TCS circuit when only one of the contacts is used.

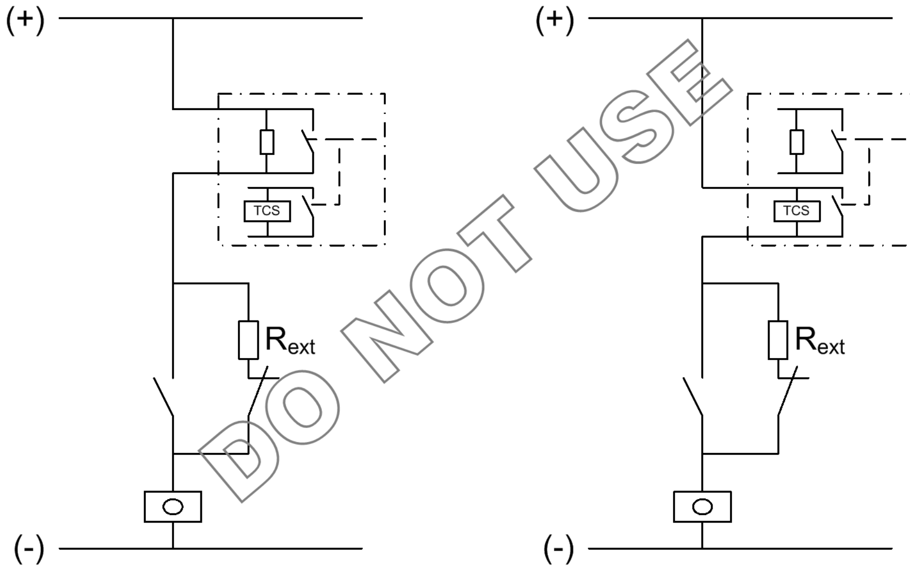


Figure 42: Incorrect connection of trip-circuit supervision

A connection of three protection IEDs with a double pole trip circuit is shown in the following figure. Only the IED R3 has an internal TCS circuit. In order to test the operation of the IED R2, but not to trip the circuit breaker, the upper trip contact of the IED R2 is disconnected, as shown in the figure, while the lower contact is still connected. When the IED R2 operates, the coil current starts to flow through the internal resistor of the IED R3 and the resistor burns immediately. As proven with the previous examples, both trip contacts must operate together. Attention should also be paid for correct usage of the trip-circuit supervision while, for example, testing the IED.

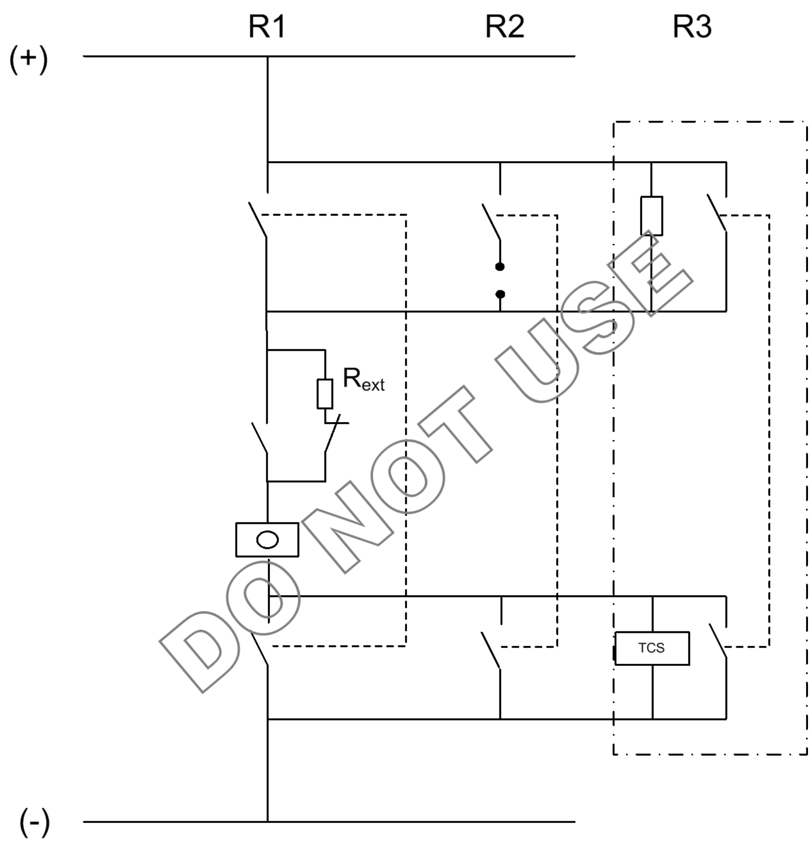


Figure 43: Incorrect testing of IEDs

7.2 Current circuit supervision CCRDIF

7.2.1 Identification

Table 38: Function identification

IEC 61850 identification:	CCRDIF
IEC 60617 identification:	MCS 3I
ANSI/IEEE C37.2 device number:	MCS 3I

7.2.2 Functionality

The current circuit supervision function CCRDIF is used for monitoring current transformer secondary circuits.

CCRDIF calculates internally the sum of phase currents (I_A, I_B and I_C) and compares the sum against the measured single reference current (I_REF). The reference current must originate from other three phase CT cores than the phase

currents (I_A, I_B and I_C) and it is to be externally summated, that is, outside the IED.

CCRDIF detects a fault in the measurement circuit and issues an alarm or blocks the protection functions to avoid unwanted tripping.

It must be remembered that the blocking of protection functions at an occurring open CT circuit means that the situation will remain and extremely high voltages will stress the secondary circuit.

7.2.3 Application

Open or short-circuited current transformer cores can cause unwanted operation in many protection functions such as differential, earth-fault current and negative sequence current functions. When currents from two independent three-phase sets of CTs, or CT cores measuring the same primary currents are available, reliable current circuit supervision can be arranged by comparing the currents from the two sets. When an error in any CT circuit is detected, the protection functions concerned can be blocked and an alarm given.

In case of high currents, the unequal transient saturation of CT cores with a different remanence or saturation factor may result in differences in the secondary currents from the two CT cores. Unwanted blocking of protection functions during the transient stage must then be avoided.

The supervision function must be sensitive and have a short operate time in order to prevent unwanted tripping from fast-acting, sensitive numerical protections in case of faulty CT secondary circuits.

Open CT circuits create extremely high voltages in the circuits which may damage the insulation and cause further problems. This must be taken into consideration especially when the protection functions are blocked.

When the reference current is not connected to the IED, the function should be turned off. Otherwise, the `FAIL` output will be activated when unbalance occur in the phase currents even though there is nothing wrong with the measurement circuit

Reference current measured with core balanced current transformer

The function compares the sum of phase currents with the current measured with the core balanced CT.

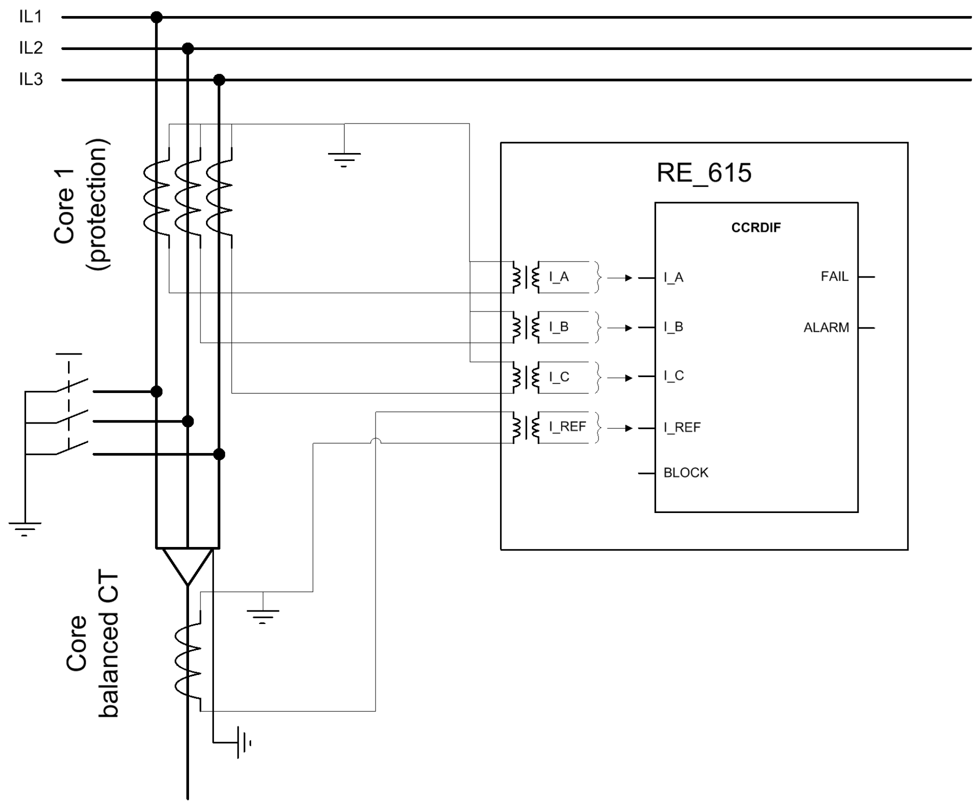


Figure 44: Connection diagram for reference current measurement with core balanced current transformer

Current measurement with two independent three-phase sets of CT cores

The figures show diagrams of connections where the reference current is measured with two independent three-phase sets of CT cores

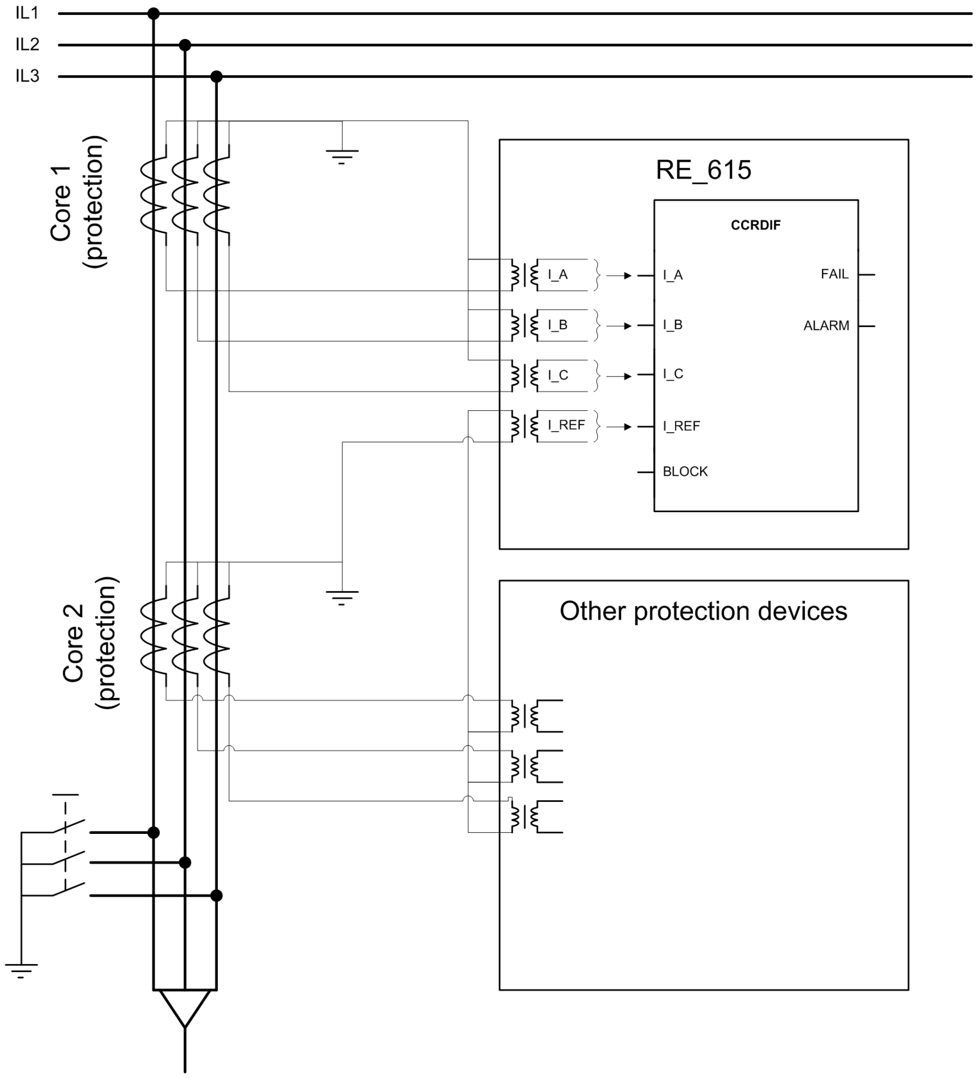


Figure 45: Connection diagram for current circuit supervision with two sets of three-phase current transformer protection cores

When using the measurement core for reference current measurement, it should be noted that the saturation level of the measurement core is much lower than with the protection core. This should be taken into account when setting the current circuit supervision function.

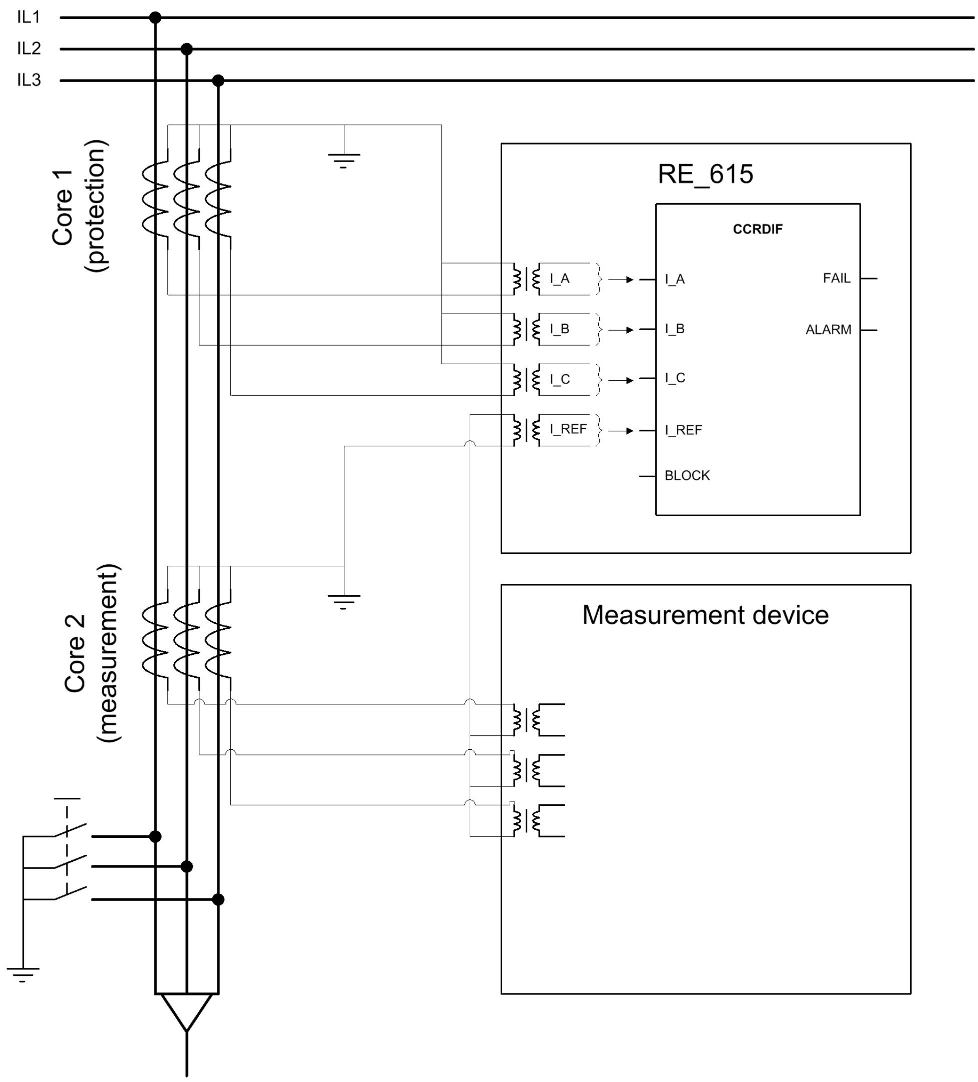


Figure 46: Connection diagram for current circuit supervision with two sets of three-phase current transformer cores (protection and measurement)

Example of incorrect connection

The currents must be measured with two independent cores, that is, the phase currents must be measured with a different core than the reference current. A connection diagram shows an example of a case where the phase currents and the reference currents are measured from the same core.

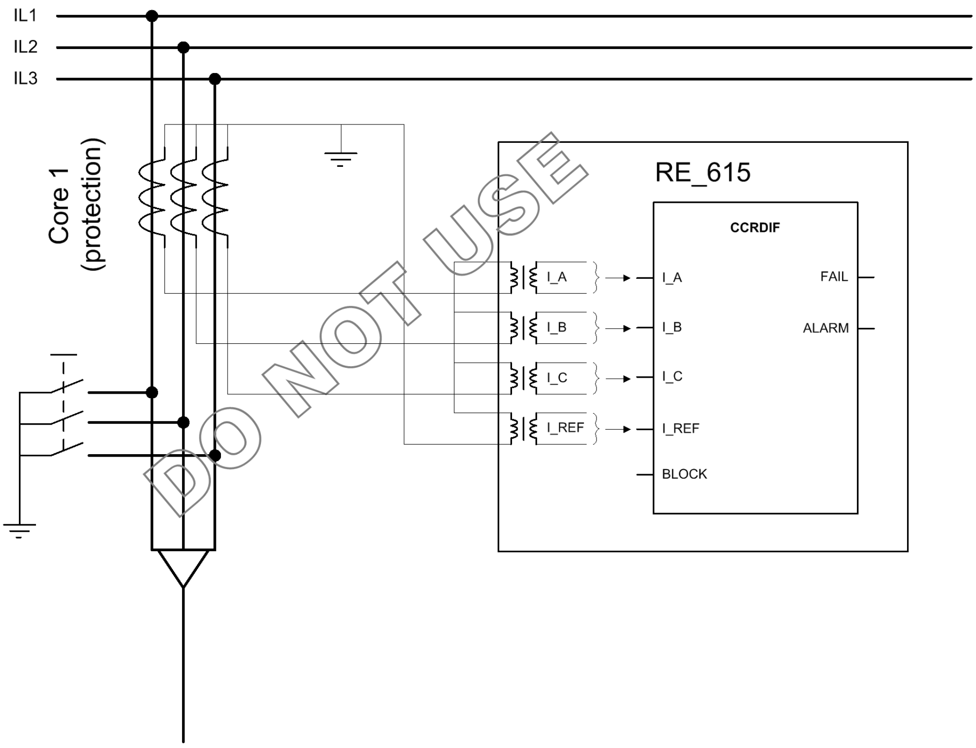


Figure 47: Example of incorrect reference current connection

7.3 Protection communication supervision PCSRTPC

7.3.1 Identification

Table 39: Function identification

IEC 61850 identification:	PCSRTPC
IEC 60617 identification:	PCS
ANSI/IEEE C37.2 device number:	PCS

7.3.2 Functionality

The protection communication supervision function PCSRTPC monitors the protection communication channel. PCSRTPC blocks the line differential protection functions when interference in the protection communication channel is detected. The blocking takes place automatically for the LNPLDF and BSTGGIO functions which are dependent on the continuous availability of the protection communication channel.

The protection communication channel is continuously monitored by PCSRTPC. The function detects missing or delayed protection telegrams. Protection telegrams are used for transferring the sampled analog and other protection related data. Missing or delayed protection telegrams can jeopardize the demand operate speed of the differential protection.

When a short-term interference is detected in the protection communication channel, the function issues a warning and the line differential functions are automatically and internally blocked. PCSRTPC reacts fast for the protection communication interferences and the blocking takes place within one fundamental network period, in case interruption is detected. When a severe and long lasting interference or total interruption in the protection communication channel is detected, an alarm is issued (after a five-second delay). The protection communication supervision quality status is exchanged continuously online by the local and remote PCSRTPC instances. This ensures that both local and remote ends protection blocking is issued coordinately. This further enhances the security of the line differential protection by forcing both line end IEDs to the same blocking state during a protection communication interference, even in cases where the interference is detected with only one line end IED. There is also the *Reset delay time* settings parameter available which is used for changing the required interference-free time before releasing the line-differential protection back in operation after a blocking due to an interference in communication.

7.3.3 Application

Communication principle

Analog samples, trip-, start- and user programmable signals are transferred in each protection telegram and the exchange of these protection telegrams is done eight times per power system cycle (every 2.5 ms when F_n = 50 Hz).

Master-Master communication arrangement is used in the two-terminal line differential solution. Current samples are sent from both line ends and the protection algorithms are also executed on both line ends. The direct-intertrip, however, ensures that both ends are always operated simultaneously.

Time synchronization

In numerical line differential protection, the current samples from the protections which are located geographically apart from each other must be time coordinated so that the current samples from both ends of the protected line can be compared without introducing irrelevant errors. The time coordination requires an extremely high accuracy.

As an example, an inaccuracy of 0.1 ms in a 50 Hz system gives a maximum amplitude error of approximately around 3 percent. An inaccuracy of 1 ms gives a maximum amplitude error of approximately 31 percent. The corresponding figures for a 60 Hz system are 4 and 38 percent respectively.

In the IED, the time coordination is done with an echo method. The IEDs create their own time reference between each other so that the system clocks do not need to synchronize.

The figure shows that in the time synchronization the transmission time to send a message from station B to station A, T1→T2, and the time to receive a message from A to B, T4→T5, are measured. The station A IED delay from the sampling to the start of send, T3→T4, and the local delay from receive to the station B IED sampling T5→T6 time, are also measured for the station B IED, and vice versa. This way the time alignment factor for the local and remote samples is achieved.

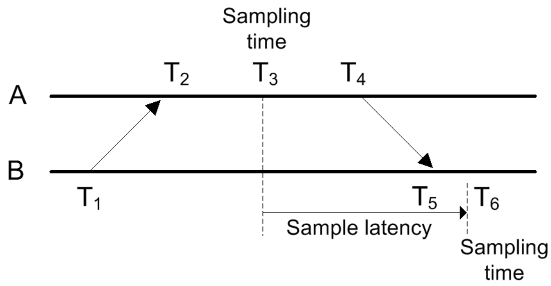


Figure 48: Measuring sampling latency

$$P_d = \frac{(T_2 - T_1) + (T_5 - T_4)}{2}$$

(Equation 3)

$$S_d = P_d + (T_4 - T_3) + (T_6 - T_5)$$

(Equation 4)

The sampling latency S_d is calculated for each telegram on both ends. The algorithm assumes that the one-way propagation delay P_d is equal for both directions.

The echo method without GPS can be used in telecommunication transmission networks as long as delay symmetry exists, that is, the sending and receiving delays are equal.

Section 8 Measurement functions

8.1 Basic measurements

8.1.1 Three-phase current CMMXU

8.1.1.1 Identification

Table 40: Function identification

IEC 61850 identification:	CMMXU
IEC 60617 identification:	3I
ANSI/IEEE C37.2 device number:	3I

8.1.2 Sequence current CSMSQI

8.1.2.1 Identification

Table 41: Function identification

IEC 61850 identification:	CSMSQI
IEC 60617 identification:	I1, I2, I0
ANSI/IEEE C37.2 device number:	I1, I2, I0

8.1.3 Functions

The three-phase current measurement function, CMMXU, is used for monitoring and metering the phase currents of the power system.

The sequence current measurement, CSMSQI, is used for monitoring and metering the phase sequence currents.

The information of the measured quantity is available for the operator both locally in LHMI and remotely to a network control center via communication.

8.1.4 Measurement function applications

The measurement functions are used for power system measurement, supervision, and reporting to LHMI, a monitoring tool within PCM600, or to the station level, for example, via IEC 61850. The possibility to continuously monitor the measured values

of active power, reactive power, currents, voltages, frequency, power factors and so on, is vital for efficient production, transmission, and distribution of electrical energy. It provides a fast and easy overview of the present status of the power system to the system operator. Additionally, it can be used during testing and commissioning of protection and control relays to verify the proper operation and connection of instrument transformers; that is, current transformers (CTs) and voltage transformers (VTs). The proper operation of the relay analog measurement chain can be verified during normal service by a periodic comparison of the measured value from the relay to other independent meters.

When the zero signal is measured, the noise in the input signal can still produce small measurement values. The zero point clamping function can be used to ignore the noise in the input signal and, hence, prevent the noise to be shown in the user display. Zero clamping is done for the measured analog signals and angle values.

The demand values can be used to neglect sudden changes in the measured analog signals when monitoring long time values for the input signal. The demand values are linear average values of the measured signal over a settable demand interval. The demand values are calculated for the measured analog three-phase current signals. The demand value calculation reports a new value when the demand interval has elapsed.

The limit supervision indicates if the measured signal exceeds the set limits by activating the alarm/warning outputs of the function. These outputs can be used to configure the reporting function (events). The supervision function has four different limits:

- low alarm limit
- low warning limit
- high warning limit
- high alarm limit

There is an exception in limit supervision concerning the residual current and the residual voltage measurement: only high alarm limits are available. In three-phase current measurement, the alarm/high indications are given for the phase that has the maximum measured value. However, a range indication is given to each phase.

The deadband supervision reports a new measurement value if the input signal has gone out of the deadband state. The deadband supervision can be used in value reporting between the measurement point and operation control. When the deadband supervision is properly configured, it will help in keeping the communication load in minimum and yet measurement values will be reported frequently enough.

8.2 Disturbance recorder

8.2.1 Functionality

The IED is provided with a disturbance recorder featuring up to 12 analog and 64 binary signal channels. The analog channels can be set to record either the waveform or the trend of the currents and voltage measured.

The analog channels can be set to trigger the recording function when the measured value falls below or exceeds the set values. The binary signal channels can be set to start a recording on the rising or the falling edge of the binary signal or both.

By default, the binary channels are set to record external or internal relay signals, for example the start or trip signals of the relay stages, or external blocking or control signals. Binary relay signals such as a protection start or trip signal, or an external relay control signal over a binary input can be set to trigger the recording.

The recorded information is stored in a non-volatile memory and can be uploaded for subsequent fault analysis.

8.2.2 Application

The disturbance recorder is used for post-fault analysis and for verifying the correct operation of protection IEDs and circuit breakers. It can record both analog and binary signal information. The analog inputs are recorded as instantaneous values and converted to primary peak value units when the IED converts the recordings to the COMTRADE format.

COMTRADE is the general standard format used in storing disturbance recordings.

The binary channels are sampled once per task execution of the disturbance recorder. The task execution interval for the disturbance recorder is the same as for the protection functions. During the COMTRADE conversion, the digital status values are repeated so that the sampling frequencies of the analog and binary channels correspond to each other. This is required by the COMTRADE standard.

The disturbance recorder follows the 1999 version of the COMTRADE standard and uses the binary data file format.

Section 9 Control functions

9.1 Circuit breaker control CBXCBR

9.1.1 Identification

Table 42: Function identification

IEC 61850 identification:	CBXCBR
IEC 60617 identification:	I<->0 CB
ANSI/IEEE C37.2 device number:	I<->0 CB

9.1.2 Functionality

The circuit breaker control function CBXCBR is intended for circuit breaker control and status information purposes. This function executes commands and evaluates block conditions and different time supervision conditions. The function performs an execution command only if all conditions indicate that a switch operation is allowed. If erroneous conditions occur, the function indicates an appropriate cause value. The function is designed according to the IEC 61850-7-4 standard with logical nodes CILO, CSWI and XCBR.

The circuit breaker control function has an operation counter for closing and opening cycle. The operator can read and write the counter value remotely from an operator place or via LHMI.

9.1.3 Application

In the field of distribution and sub-transmission automation, reliable control and status indication of primary switching components both locally and remotely is in a significant role. They are needed especially in modern remotely controlled substations.

Control and status indication facilities are implemented in the same package with CBXCBR. When primary components are controlled in the energizing phase, for example, the user must ensure that the control commands are executed in a correct sequence. This can be achieved, for example, with interlocking based on the status indication of the related primary components. An example of how the interlocking on substation level can be applied by using the IEC61850 GOOSE messages between feeders is as follows:

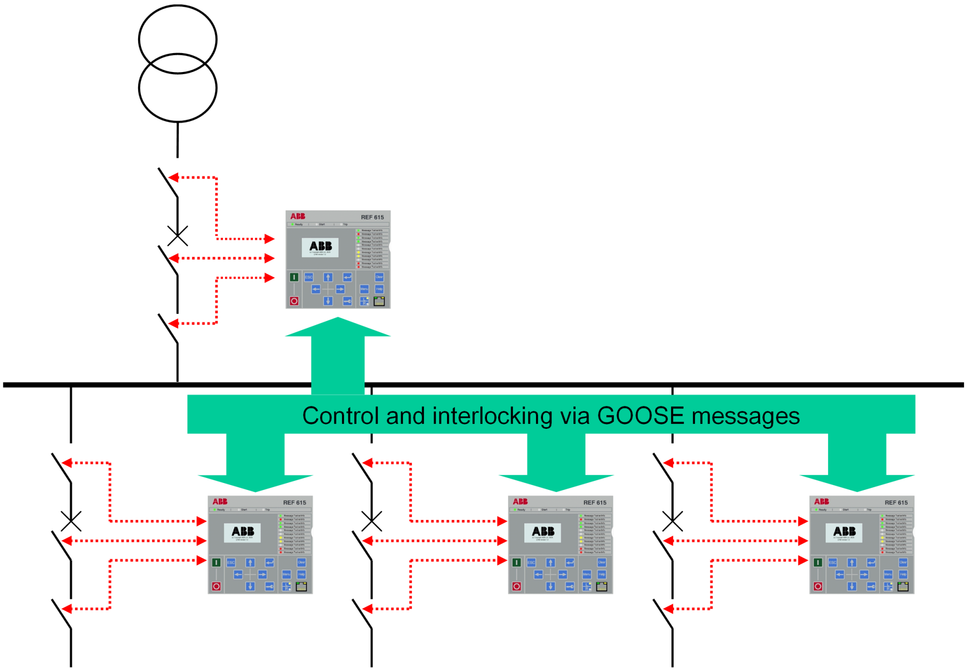


Figure 49: Status indication based interlocking via GOOSE messaging

9.2 Disconnector DCSXSWI and earthing switch ESSXSWI

9.2.1 Identification

Table 43: Function identification

IEC 61850 identification:	DCSXSWI	ESSXSWI
IEC 60617 identification:	I<->0 DC	I<->0 ES
ANSI/IEEE C37.2 device number:	I<->0 DC	I<->0 ES

9.2.2 Functionality

The functions DCSXSWI and ESSXSWI indicate remotely and locally the open, close and undefined states of the disconnector and earthing switch. The functionality of both is identical, but each one is allocated for a specific purpose visible in the function names. For example, the status indication of disconnectors or circuit breaker truck can be monitored with the DCSXSWI function.

The functions are designed according to the IEC 61850-7-4 standard with the logical node XSWI.

9.2.3 Application

In the field of distribution and sub-transmission automation, the reliable control and status indication of primary switching components both locally and remotely is in a significant role. These features are needed especially in modern remote controlled substations. The application area of DCSXSWI and ESSXSWI functions covers remote and local status indication of, for example, disconnectors, air-break switches and earthing switches, which represent the lowest level of power switching devices without short-circuit breaking capability.

9.3 Interaction between control modules

A typical substation feeder with IED control function consists of a combination of logical nodes or functions:

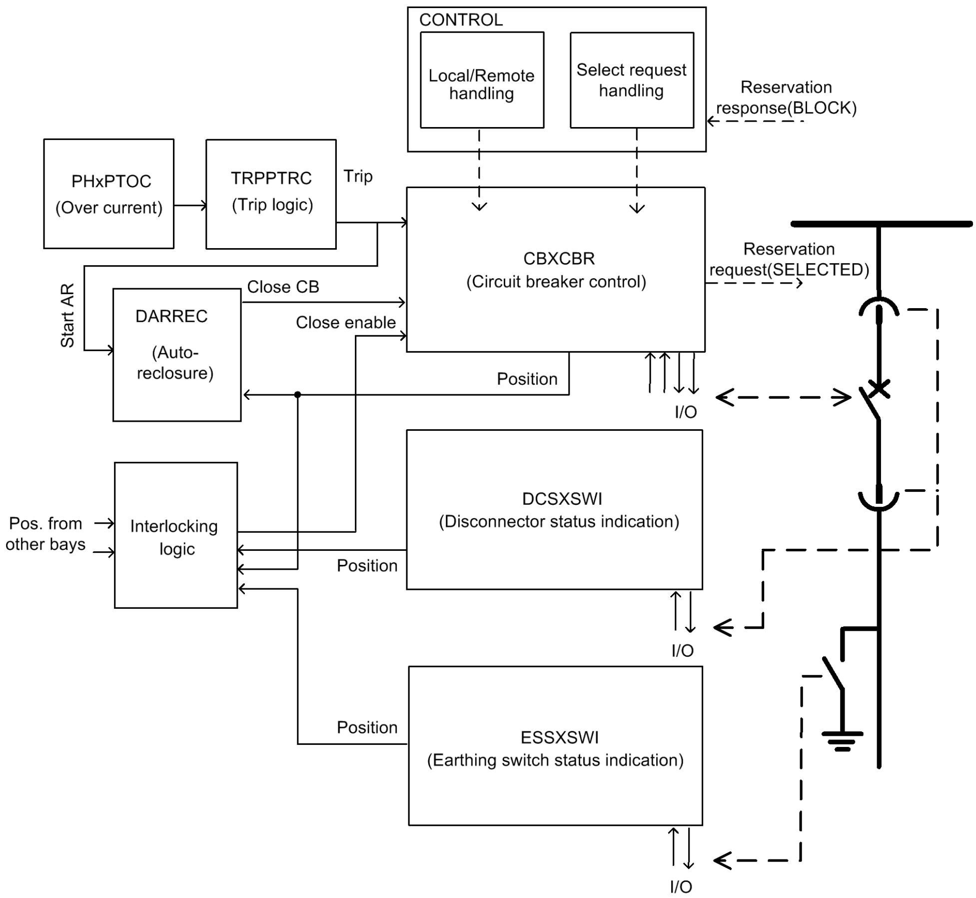


Figure 50: Example overview of interactions between functions in a typical distribution feeder

Section 10 Requirements for measurement transformers

10.1 Current transformers

10.1.1 Current transformer requirements for non-directional overcurrent protection

For reliable and correct operation of the overcurrent protection, the CT has to be chosen carefully. The distortion of the secondary current of a saturated CT may endanger the operation, selectivity, and co-ordination of protection. However, when the CT is correctly selected, a fast and reliable short circuit protection can be enabled.

The selection of a CT depends not only on the CT specifications but also on the network fault current magnitude, desired protection objectives, and the actual CT burden. The protection relay settings should be defined in accordance with the CT performance as well as other factors.

10.1.1.1 Current transformer accuracy class and accuracy limit factor

The rated accuracy limit factor (F_n) is the ratio of the rated accuracy limit primary current to the rated primary current. For example, a protective current transformer of type 5P10 has the accuracy class 5P and the accuracy limit factor 10. For protective current transformers, the accuracy class is designed by the highest permissible percentage composite error at the rated accuracy limit primary current prescribed for the accuracy class concerned, followed by the letter "P" (meaning protection).

Table 44: Limits of errors according to IEC 60044-1 for protective current transformers

Accuracy class	Current error at rated primary current (%)	Phase displacement at rated primary current		Composite error at rated accuracy limit primary current (%)
		minutes	centiradians	
5P	±1	±60	±1.8	5
10P	±3	-	-	10

The accuracy classes 5P and 10P are both suitable for non-directional overcurrent protection. The 5P class provides a better accuracy. This should be noted also if there are accuracy requirements for the metering functions (current metering, power metering, and so on) of the relay.

The CT accuracy primary limit current describes the highest fault current magnitude at which the CT fulfils the specified accuracy. Beyond this level, the secondary current of the CT is distorted and it might have severe effects on the performance of the protection relay.

In practise, the actual accuracy limit factor (F_a) differs from the rated accuracy limit factor (F_n) and is proportional to the ratio of the rated CT burden and the actual CT burden.

The actual accuracy limit factor is calculated using the formula:

$$F_a \approx F_n \times \frac{|S_{in} + S_n|}{|S_{in} + S|}$$

F_n	the accuracy limit factor with the nominal external burden S_n
S_{in}	the internal secondary burden of the CT
S	the actual external burden

10.1.1.2 Non-directional overcurrent protection

The current transformer selection

Non-directional overcurrent protection does not set high requirements on the accuracy class or on the actual accuracy limit factor (F_a) of the CTs. It is, however, recommended to select a CT with F_a of at least 20.

The nominal primary current I_{1n} should be chosen in such a way that the thermal and dynamic strength of the current measuring input of the relay is not exceeded. This is always fulfilled when

$I_{1n} > I_{kmax} / 100$,

I_{kmax} is the highest fault current.

The saturation of the CT protects the measuring circuit and the current input of the relay. For that reason, in practice, even a few times smaller nominal primary current can be used than given by the formula.

Recommended start current settings

If I_{kmin} is the lowest primary current at which the highest set overcurrent stage of the relay is to operate, then the start current should be set using the formula:

Current start value < 0.7 x (I_{kmin} / I_{1n})

I_{1n} is the nominal primary current of the CT.

The factor 0.7 takes into account the protection relay inaccuracy, current transformer errors, and imperfections of the short circuit calculations.

The adequate performance of the CT should be checked when the setting of the high set stage O/C protection is defined. The operate time delay caused by the CT saturation is typically small enough when the relay setting is noticeably lower than F_a.

When defining the setting values for the low set stages, the saturation of the CT does not need to be taken into account and the start current setting is simply according to the formula.

Delay in operation caused by saturation of current transformers

The saturation of CT may cause a delayed relay operation. To ensure the time selectivity, the delay must be taken into account when setting the operate times of successive relays.

With definite time mode of operation, the saturation of CT may cause a delay that is as long as the time the constant of the DC component of the fault current, when the current is only slightly higher than the starting current. This depends on the accuracy limit factor of the CT, on the remanence flux of the core of the CT, and on the operate time setting.

With inverse time mode of operation, the delay should always be considered as being as long as the time constant of the DC component.

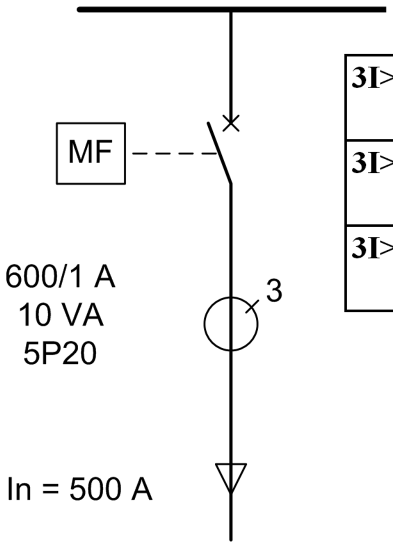
With inverse time mode of operation and when the high-set stages are not used, the AC component of the fault current should not saturate the CT less than 20 times the starting current. Otherwise, the inverse operation time can be further prolonged. Therefore, the accuracy limit factor F_a should be chosen using the formula:

F_a > 20**Current start value* / I_{1n}

The *Current start value* is the primary pickup current setting of the relay.

10.1.1.3 Example for non-directional overcurrent protection

The following figure describes a typical medium voltage feeder. The protection is implemented as three-stage definite time non-directional overcurrent protection



3I>	**1200 A** **0.75 s**	**2.00 x I_{2n}** **0.75 s**
3I>>	**1800A** **0.50 s**	**3.00 x I_{2n}** **0.50 s**
3I>>>	**3500 A** **0.20 s**	**5.83 x I_{2n}** **0.20 s**

Figure 51: Example of three-stage overcurrent protection

The maximum three-phase fault current is 41.7 kA and the minimum three-phase short circuit current is 22.8 kA. The actual accuracy limit factor of the CT is calculated to be 59.

The start current setting for low-set stage (3I>) is selected to be about twice the nominal current of the cable. The operate time is selected so that it is selective with the next relay (not visible in the figure above). The settings for the high-set stage and instantaneous stage are defined also so that grading is ensured with the downstream protection. In addition, the start current settings have to be defined so that the relay operates with the minimum fault current and it does not operate with the maximum load current. The settings for all three stages are as in the figure above.

For the application point of view, the suitable setting for instantaneous stage (I>>>) in this example is 3 500 A (5.83 x I_{2n}). For the CT characteristics point of view, the criteria given by the current transformer selection formula is fulfilled and also the relay setting is considerably below the F_a. In this application, the CT rated burden could have been selected much lower than 10 VA for economical reasons.

10.1.2 Current transformer requirements for line differential protection

In line differential application, the CT has to be chosen carefully. The purpose of the CT requirements is to secure the stability of the IED at high through-currents, and also the quick and sensitive operation at faults occurring in the protected area where the fault currents may be high. Normally, when the residual flux of the current transformer is high, it is not possible to dimension the CTs so that they repeat currents with high DC components without saturating. The differential IED operates reliably even when the CTs are partially saturated.

10.1.2.1 Current transformer accuracy class and accuracy limit factor

The accuracy class recommended for the CTs to be used with the line differential function LNPLDF is 5P in which the limit of the current error at the rated primary current is one percent and the limit of the phase displacement is 60 minutes. The limit of the composite error at the rated accuracy limit primary current is five percent.

The approximate value of the accuracy limit factor F_a corresponding to the actual CT burden is calculated using the formula:

$$F_a \approx F_n \times \frac{|S_{in} + S_n|}{|S_{in} + S_a|}$$

F_n = rated accuracy limit factor at the rated burden

S_n = rated burden

S_{in} = internal burden

S_a = actual burden of the CT

More detailed considerations and dimensioning examples are presented in the CT dimensioning application note for RED615.

Section 11 Glossary

100BASE-TX	A physical media defined in the IEEE 802.3 Ethernet standard for local area networks (LANs). 100BASE-TX uses twisted-pair cabling category 5 or higher with RJ-45 connectors.
AI	Analog input
ANSI	American National Standards Institute
ASCII	American Standard Code for Information Interchange
BI	Binary input
BI/O	Binary input/output
BO	Binary output
CPU	Central processing unit
CT	Current transformer
DC	Direct current
DT	Definite time
EEPROM	Electrically Erasable Programmable Read-Only Memory
EMC	Electromagnetic compatibility
Ethernet	A large, diverse family of frame-based computer networking technologies that operate at many speeds for LANs interconnecting computing devices. Ethernet is a trademark of Xerox Corporation, Inc. and defined in the IEEE 802.3 standard in which computers access the network through a CSMA/CD protocol.
FPGA	Field Programmable Gate Array
GOOSE	Generic Object Oriented Substation Event
GPS	Global Positioning System
HMI	Human-machine interface
IEC	International Electrotechnical Commission
IEC 61850	International standard for substation communication and modelling.
IEC 61850-8-1	A communication protocol based on the IEC 61850 standard series and a standard for substation modelling.
IED	Intelligent Electronic Device

IP address	Internet protocol address is a set of four numbers between 0 and 255, separated by periods. Each server connected to the Internet is assigned a unique IP address that specifies a location for the TCP/IP protocol.
LAN	Local area network
LCD	Liquid crystal display
LED	Light-emitting diode
LHMI	Local Human-Machine Interface
LON	Local operating network
Modbus	A serial communication protocol developed by the Modicon company in 1979. Originally used for communication in PLCs and RTU devices.
Modbus TCP/IP	Modbus RTU protocol which uses TCP/IP and Ethernet to carry data between devices.
MV	Medium voltage
NPS	Negative phase sequence
PCM600	Protection and Control IED Manager
PO	Power output
PST	Parameter Setting Tool
RAM	Random access memory
RJ-45	Galvanic connector type.
ROM	Read-only memory
RS-485	Serial link according to EIA standard RS485.
RTC	Real Time Clock
RTU	Remote Terminal Unit
SCL	Substation Configuration Language
SMT	Signal Matrix Tool
SNTP	Simple Network Time Protocol
SO	Signal output
SW	Software
TCS	Trip-circuit supervision
VT	Voltage transformer
WAN	Wide area network
WHMI	Web Human-Machine Interface

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